

NEBULAR LINES IN THE SPECTRUM OF AG PEGASI

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ABSTRACT

The discussion is based on 36 high-dispersion spectrograms taken between June, 1949, and September, 1956. During this interval the 800-day cycle in the displacements of emission lines continued, while resemblance to a typical symbiotic object increased. Numerous narrow bright lines of ionized metals exhibit changes in velocity of only 8 or 10 km/sec, while bright hydrogen lines vary through a range of 40 km/sec. The mean velocity from the hydrogen lines has decreased from +16 km/sec in 1915 to -27 km/sec in 1952. Shortward-displaced dark components of λ 3888 of He I are still present. Velocities from M-type absorption lines vary through a small range. The velocity range of λ 4363 of [O III] in the 800-day cycle is almost 70 km/sec, while that of λ 5007, also of [O III] is less than 20 km/sec. The difference between the two lines is probably related to differences in density in various parts of the stellar system. The observed phenomena may arise from a jet of gas of relatively high density emitting chiefly λ 4363, revolving near the center of the system and discharging into a large expanding outer zone which emits chiefly λ 5007.

My last general report on the spectrum of AG Pegasi (BD+11°46'73, HD 207757; 1900 R.A. 21^h46^m2; Dec. +12° 9'; spectrum Pec.) was prepared in 1950 (Merrill 1951*a*). Since then the 800-day cycle in the behavior of numerous emission lines has continued, while the resemblance to a typical symbiotic object has increased. The M-type absorption spectrum has gradually become more prominent. During the same interval the nebular emission lines 3869 Å of [Ne III] and 4363, 4959, 5007 Å of [O III] have become stronger; their profiles and displacements have behaved in an unexpected way.

The spectrum of AG Pegasi was photographed in 1951 at the Haute Provence Observatory by Tcheng Mao Lin and Marie Bloch (1952) and in 1953 at the McDonald Observatory by G. R. and E. Margaret Burbidge (1954). The results agree with those from spectrograms of higher dispersion taken at Mount Wilson and Palomar.

Spectrograms used in the present investigation are listed in Table 1, which overlaps somewhat lists previously published (Merrill 1951*a, b*). The designation "Ce" indicates coude plates taken with the 100-inch on Mount Wilson; "Pb" those taken with the 200-inch on Palomar Mountain. Most of the spectrograms since 1949 were taken by H. W. Babcock in his studies of the Zeeman effect in stellar spectra (Babcock 1958). I am most appreciative of Dr. Babcock's courtesy in allowing me to use not only the spectrograms but also partial measures of them made by himself and Miss Sylvia Burd.

PERMITTED LINES

Metallic lines.—As in previous years, numerous narrow emission lines of Fe II exhibit changes in velocity of only 8 or 10 km/sec in a period of about 800 days, with a mean value of -18 km/sec (see Table 1 and Fig. 1). Lines of [Fe II] are very weak.

Emission lines of various metals, including those of Mg I, II; Si I, II, IV; Ca II; Ti II; Cr II; Fe I, II; and Ni II, have been measured. Their intensities vary considerably from time to time, probably with phase in the 800-day cycle. Their velocities agree with those obtained from lines of Fe II.

Hydrogen lines.—Bright hydrogen lines in the Balmer series have continued to be strong and wide, with occasional indications of internal structure, not always symmetrical. Thus measurements for velocity are sometimes difficult and not always strictly comparable; but the main trend of the displacements is unmistakable. The velocities from

various Balmer lines agree fairly well and exhibit the usual 800-day period with a range of about 40 km/sec as in the 1940's (Table 1 and Fig. 1). The average period from 1921 to 1954 was about 792 days. The mean velocity has continued the surprising decrease previously noted (see Table 2). Some other lines, but not all of them, have moved in the same direction (see Merrill 1951*a*, Table 9 and Fig. 11). The interpretation of this decrease and of other anomalies in this complicated system is not easy.

Helium lines.—Emission lines of He I and He II remain conspicuous. Interesting differences in structure between singlet and triplet lines of He I sometimes appear; they are probably to be attributed to differences in density of the emitting gas at various points in the stellar system.

TABLE 1
SPECTROGRAMS OF AG PEGASI

PLATE	DATE	JD 2430000+	RADIAL VELOCITY (km/sec)				
			Fe II	H	[Ne III] 3869	[O III] 4363	[O III] 4959 5007
Ce 5681.....	1949 June 11	3079	-15.2	-14	.....	(+11)	(-8)
5808.....	Aug. 3	3132	-15.9	?	.....	(0)	- 1
6024.....	Nov. 12	3233	-19.	?	.....	-28	- 2
6245.....	1950 May 25	3427	-23.8	-45	.....	-54	-15
6337.....	June 29	3462	-21.4	-29	-44	-48	-18
6350.....	July 1	3464	-19.1	-36	(-28)	-50	-15
6355.....	July 2	3465	-19.5	-36	.....	-54	.....
6369.....	July 25	3488	-17.2	-28	.....	-60	-19
6377.....	July 27	3490	-17.4	-30	.....	-56	-11
6389.....	July 29	3492	-19.0	-26	.....	-51	-14
6429.....	Aug. 4	3498	-18.2	-26	-52	-60	-16
6435.....	Aug. 5	3499	-18.8	-26	-55	-58	-19
6444.....	Aug. 7	3501	-19.5	-27	-48	-60	-20
6483.....	Aug. 29	3523	-16.2	-27	.....	-51	-22
6491*.....	Aug. 30	3524	-15.6	-23	.....	-58	.....
6497*.....	Aug. 31	3525	-16.1	-26	.....	-49	.....
6540.....	Sept. 24	3549	-16.0	-22	(-72)	-50	-16
6619.....	Oct. 20	3575	-13.5	-18	(-68)	-41	-15
6696.....	Nov. 28	3614	-13.7	-13	(-61)	-35	-16
6771.....	Dec. 29	3645	-11.9	- 8	.....	-30	.....
7056.....	1951 May 25	3792	-16.6	-13	.....	(+19)	.....
7073.....	June 14	3812	-17.5	-16	.....	+ 8	-11
7136.....	July 21	3849	-19.8	-21	.....	+ 6	-19
7369*.....	Aug. 23	3882	-20.3	-21	.....	+ 3	.....
8264*.....	1952 Aug. 7	4232	.....	-49	.....	-48	.....
8370.....	Sept. 9	4265	-15.5	-34	(-32)	-54	(-19)
8468.....	Nov. 1	4318	-15.3	-23	-52	-57	-15
McD†.....	1953 May 8	4506	-16.4	-13	+ 6	+ 2	.....
Pb 946*.....	May 30	4518	-15.9	(-12)	(+ 1)	+ 4	.....
994*.....	June 27	4556	-19.5	-15	+ 6	+12	.....
1057*.....	July 25	4584	-17.7	-14	+ 4	+11	.....
1178*.....	Oct. 20	4671	-16.0	-16	.....	+13	(- 7)
1582*.....	1954 July 10	4934	.....	-54	-30	-38	.....
Ce 9366*.....	Aug. 13	4968	.....	-49	.....	.....	.....
Ce 9372.....	Aug. 15	4970	-23.3	-44	-39	-43	-20
9374*.....	Sept. 7	4993	.....	-51	-40	-32	.....
Pb 2841*.....	1956 Sept. 21	5738	-26.7	(-51)	-32	-36	.....

* Dispersion 4.5 Å/mm. All other Mount Wilson plates (Ce) have 10 Å/mm.

† McDonald Observatory, dispersion 13 Å/mm (Burbidge and Burbidge 1954).

The remarkable shortward-displaced dark components of He I 3888 Å continue to be visible, but the pattern changes noticeably from time to time. Plates taken in 1953, 1954, and 1956 show several well-marked components, with displacements comparable with those previously reported (Merrill 1951*b*). The component with displacement about -72 km/sec is persistent.

Emission lines of He II and N III are wide and diffuse. The He II line 4686 Å is quite intense.

M-type absorption lines.—The narrow absorption lines of the M-type spectrum have gradually been emerging from blending with the early-type continuum until now, longward of about 4400 Å, many can be accurately measured. Available measurements of recent plates are in Table 3. The first and third plates were measured by Miss Sylvia Burd, the second by P. W. Merrill. These and previous measures (Merrill 1951*a*, Table 7) show a range from -11 to -21 km/sec, with a mean value about -16 km/sec. Thus the general behavior of the velocities does not seem to differ greatly from that of the metallic emission lines. The data are not sufficiently extensive to make certain of periodic cycles. Several band heads of TiO are visible in low intensity.

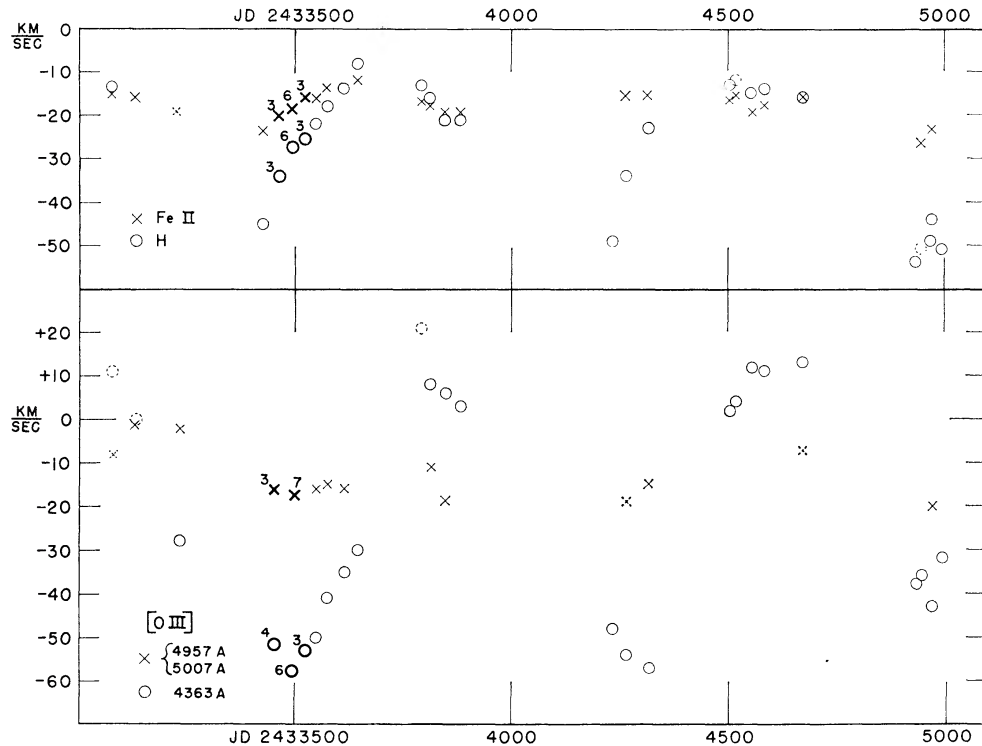


FIG. 1.—Radial velocities derived from bright lines. Normal places are indicated by numerals showing the number of plates included.

TABLE 2
MEAN VELOCITIES FROM BRIGHT HYDROGEN LINES

	Km/sec		Km/sec
1915.....	+16	1946	- 8
1926.....	+12	1952	-27
1939.....	- 4		

FORBIDDEN LINES

Emission lines of [Fe II] were observed with low dispersion in 1915 (Merrill 1916) and in the 1920's (Merrill 1929) but recently have been very weak. The [N II] lines in the red, 6548, 6583 Å, also were regularly photographed for many years but were not visible on plates taken in 1953 and 1954, perhaps because of the increasing intensity of the M-type spectrum. On the other hand, 4363, 4959, 5007 Å of [O III], first recognized in 1943 (Merrill 1951*a*), together with 3869 Å [Ne III], have become increasingly prominent since 1950 and have been regularly measured on suitable high-dispersion spectrograms taken with the 100-inch and 200-inch telescopes (see Table 1). Some or all of them were photographed in 1951 at the Haute Provence Observatory (Tcheng Mao Lin and Marie Bloch 1952) and in 1953 at the McDonald Observatory (Burbidge and Burbidge 1954).

TABLE 3
VELOCITIES FROM M-TYPE ABSORPTION LINES

Plate	Date	Region	No. Lines	Velocity (km/sec)	Prob. Error (km/sec)
Pb 1168...	Sept. 28, 1953	Red	35	-21.1	0.2
Ce 9372...	Aug. 15, 1954	Blue	16	-14.4	0.4
Pb 1751 .	Oct. 8, 1954	Red	25	-11.8	0.3

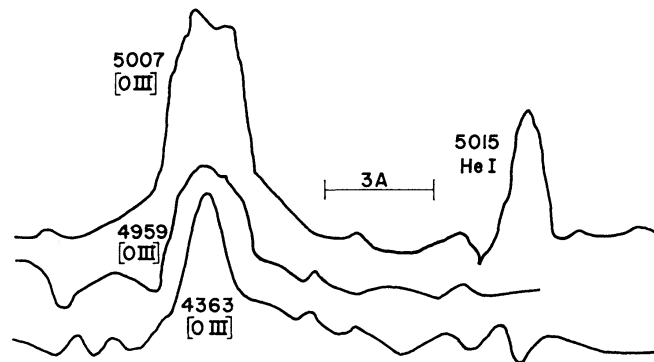


FIG. 2.—Tracings of emission lines on plate Ce 9372, August 15, 1954

Velocities from the slightly diffuse 4363 Å [O III] line vary in the 800-day cycle from about +10 to -58 km/sec, with a mean value about -24 km/sec (see Table 1 and Fig. 1). The [Ne III] line 3869 Å is weaker and sometimes difficult to bisect, but within errors yields the same velocity-curve as 4363 Å. The amplitude of this curve is noticeably greater than that from the hydrogen lines, and the phase is displaced by about +150 days, or 0.18 period. A similar displacement in phase has been found in several other symbiotic stars and is apparently characteristic of this queer group (Merrill 1958).

Lines 4959 and 5007 Å of [O III] behave quite differently from 4363 Å. The 4959 Å line is weak and sometimes difficult to measure, but, as far as can be determined, its behavior is the same as that of the stronger line 5007 Å. Both lines are wide, with nearly rectangular profiles noticeably different from that of 4363 Å, which has a narrower rounded maximum (see Fig. 2). The mean width of the rectangular portion of 5007 Å, measured with the microscope on nine plates, is 1.91 ± 0.03 Å; of 4959 Å, measured on two plates, 1.9 Å. The corresponding difference in the radial velocity is 114 km/sec. The measured velocity of the centers of 4959 and 5007 Å (Table 1 and Fig. 1), however,

shows only a small range, possibly from -2 to -19 km/sec, with a mean value near -14 km/sec.

What circumstances could cause the marked differences in behavior between the two lines of [O III] 4363 and 5007 Å? The upper level of λ 4363 is $2p^2\ ^1S_0$ at 5.33 eV; that of λ 5007 is $2p^1\ ^1D_2$ at 2.50 eV. Because the transition probability of λ 5007 is only one-eighthieth that of λ 4363, λ 5007 will be favored by an increase in the mean free time between collisions of O III ions with various particles; that is to say, it will be favored by lower density and/or lower temperatures. Moreover, at lower temperatures, λ 5007 will be favored also by the Boltzmann distribution because its upper level is 2.83 eV below that of λ 4363. These facts indicate that λ 5007 comes, at least partly, from a volume of gas of lower density and/or temperature than that which produces λ 4363. If some kind of expansion is involved, this seems to mean that λ 4363 is emitted near the center, λ 5007 in some outer zone. The width of λ 5007 indicates that on any one plate it displays an integration of virtually all the velocities shown by λ 4363 throughout the 800-day cycle.

The He I lines apparently offer a less extreme example of the effect of differences in density. The amplitude of the velocity-curve derived from the singlet lines is only about

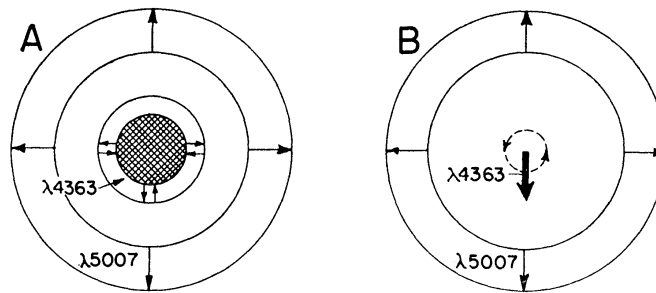


FIG. 3.—Hypotheses to explain displacements and profiles of the nebular lines λ 4363 and λ 5007 of [O III]. *A*, pulsation; *B*, hose effect.

two-thirds that from the triplet lines (Merrill 1951*a*, Fig. 6). This relationship is in the same sense as that shown by the [O III] lines, that is, lines favored by low density show smaller amplitudes of radial-velocity variation. Because lines of He I are wide and sometimes unsymmetrical, attempts to determine their positions by “bisection” with a micrometer wire are not entirely satisfactory; the profiles should be studied in more detail.

The differences in behavior of λ 4363 and λ 5007 of [O III] might arise in either of two ways:

1. Similar velocities are actually present in the stellar system for both lines, but in λ 4363 some of them are blocked off from our view. This could happen if the emitting layer were a close mantle around an opaque sphere; we would then see the half toward us, while the other half would be hidden. In Figure 3, *A*, λ 4363 comes from the close mantle, while λ 5007 comes from a sphere (or ring) of low optical density so large that the front and rear halves are almost equally represented on our spectrograms. Pulsations in this sphere might conceivably lead to the observed effects.

A sphere pulsating in a period of 800 days, however, does not seem likely. For one thing, the intrinsic brightness of gasses emitting these forbidden lines must be low and thus the volumes concerned very large. Hence it would take an improbably large central mass to control the observed velocities. Moreover, during the cycle there should be a considerable variation in the widths of the lines; such a variation in the nebular lines has not been observed. (Variations in the structure of lines of H and He I need closer

study.) It is barely possible that a pulsating inner mantle emitting λ 4363 feeds a much larger outer zone emitting λ 5007 in which periodic changes are relatively small.

2. The second possibility is that a definitely directed stream of gas emitting chiefly λ 4363 revolves near the center of the system and feeds a large expanding outer zone which emits chiefly λ 5007 (Fig. 3, *B*). This hypothesis resembles that suggested by Kuiper (1941, Fig. 13) and by Struve and Huang (1957, Fig. 4) to explain certain periodic phenomena in the peculiar bright-line eclipsing variable β Lyrae. Dr. Cecilia Payne-Gaposchkin, I believe, called it the "hose effect." Such a directed stream of gas would presumably be controlled by gravitational interactions between components of a binary system and thus would revolve in the same period as those components.

In one generation, AG Pegasi has changed from a P Cygni star into a symbiotic object. Further observations of the increasingly dominant symbiotic phase would certainly be interesting and might be quite helpful in stimulating and guiding general hypotheses of active stellar atmospheres; they might even suggest useful ideas concerning the behavior of various emission lines in planetary nebulae.

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