STARS NEARER THAN FIVE PARSECS

PETER VAN DE KAMP
Sproul Observatory, Swarthmore College

The list of 39 stars in Table I is a revision of the list[1] published in 1940. The stars are arranged in order of decreasing parallax, component stars being designated by *A, B, C,* in order of decreasing brightness. Nos. 9, 13, and 32 are newcomers to the list. No. 39, 70 Ophiuchi, has been added because of its special interest, although the value of its parallax is not quite 0″.2.

Of the 39 stars, 16 are known to be multiple. They are the sun and its dependents, 2 visual triple stars, 8 visual binaries, and 5 "single" stars (Nos. 3, 4, 20, 21, and 32), all red dwarfs now recognized as unresolved astrometric binaries. One component of the visual double No. 12 is also an unresolved astrometric binary. The unseen companions are indicated by asterisks. The existence of several more is suspected .

The masses of the seven visual doubles whose orbital period, *P,* and semi-axis major, *a,* are well established are found from the relation

$$M + m = a^3 P^{-2},$$

using the conventional astronomical units of mass, space, and time. The total mass is divided between the two components by localizing the center of mass through its constant proper motion. The details of this problem have been discussed elsewhere;[2] the results are given in Table II. Because of the relatively accurate evaluation of the linear value of the semi-axis major, *a,* these stellar masses are among those most accurately known. The observations of the remaining three visual binaries do not yet permit computation of their orbital elements. Two of the binaries, Σ 2398 and Groombridge 34, with apparent separations of 16″ and 38″, respectively, have periods which are very long and at present indeterminate. For the third, Wolf 424,

[1] *Pop. Astr.,* **48,** 297, 1940.
[2] *Ibid.,* **51,** 175, 1943.

early determination of the period may be expected; Reuyl, who discovered the close visual duplicity from photographic plates, reports appreciable orbital motion between the years 1938 and 1941.

Attention is drawn to the analogy and difference between the spectroscopic and the astrometric study of unresolved binaries. The spectroscopic binary with both spectra visible has its astrometric counterpart in a double star with the two components separated on the photographic plate; the spectroscopic binary with one spectrum visible corresponds to the astrometric pair with one companion invisible. The comparison spectrum corresponds to the background of astrometric reference stars; neither is required for studying the relative orbit of two components if both spectra or both stars are visible. If for an astrometric binary the separation of the components is not much less than the diameter of the photographic star images (1″ to 3″), measurements of the elongated blend are of questionable significance. Experience with known visual binaries having separations well below the photographic resolution has shown, however, that, although no elongation of the blended image is visible, the measured effective position of the image relative to a background of reference stars closely represents the weighted light-center of the components.

For the unresolved astrometric binaries in Table I partial information about the masses can be obtained from the space-time dimensions of their photocentric orbits.[3,4] Neither spectroscopic observations nor visual detection are yet available, so that only approximate values for the lower limits of the companion masses can be obtained. The first photographic discovery of an invisible companion was that of Ross 614 made by Reuyl[5] in 1936. The period of this pair seems to be more than 15 years,[4] the mass of the unseen companion about 0.1 ⊙. To BD+20°2465, Reuyl[6] assigns a tentative period of 26.5 years,

[3] *Pub. A.S.P.*, **55**, 263, 1943.

[4] *A.J.*, **51**, 7, 1944.

[5] *A.J.*, **45**, 133, 1936; *Pub. Amer. Astron. Soc.*, **10**, 143, 1941.

[6] *Ap. J.*, **97**, 186, 1943.

TABLE

STARS NEARER THAN

No.	Name	1900 R.A.	1900 Decl.	Visual Magnitude and Spectrum						Annual Proper Motion
				A		*B*		*C*		
1....	Sun	......	......	...	G0	...	...	..	....	....
		h m								″
2....	α Centauri	14 32.8	—60°25′	0.3	G4	1.7	K1	11	....	3.68
3....	Barnard's star	17 52.9	+ 4 25	9.7	M5	*		..	....	10.30
4....	Lalande 21185	10 57.9	+36 38	7.6	M2	*		..	....	4.78
5....	Wolf 359	10 51.6	+ 7 37	13.5	M5e	...	...	..	....	4.84
6....	Sirius	6 40.7	—16 35	—1.6	A0	7.1	A5	..	....	1.32
7....	Ross 154	18 43.6	—23 57	11	M4e	...	...	..	....	.67
8....	Ross 248	23 37.0	+43 40	12.2	M6	...	...	..	....	1.58
9....	Luyten 789-6	22 33.0	—15 52	12.3	M5e	...	...	..	....	3.27
10....	ε Eridani	3 28.2	— 9 48	3.8	K0	...	...	..	....	.97
11....	Procyon	7 34.1	+ 5 29	0.5	F3	10.8	...	..	....	1.25
12....	61 Cygni	21 2.4	+38 15	5.6	K5	6.3	K6	*		5.22
13....	Ross 128	11 42.5	+ 1 23	11.1	M5	...	...	..	....	1.40
14....	ε Indi	21 55.7	—57 12	4.7	K5	...	...	..	....	4.67
15....	τ Ceti	1 39.4	—16 27	3.6	K0	...	...	..	....	1.92
16....	Σ 2398	18 41.8	+59 29	8.9	M4	9.7	M5	..	....	2.29
17....	BD—12°4523	16 24.7	—12 25	9.7	M4	...	...	..	....	1.24
18....	Groombridge 34	0 12.7	+43 27	8.1	M1	10.9	M6	..	....	2.91
19....	Lacaille 9352	22 59.4	—36 26	7.4	M2	...	...	..	....	6.87
20....	BD+5°1668	7 22.4	+ 5 32	10.1	M4	*		..	....	3.73
21....	Ross 614	6 24.3	— 2 44	11	M4e	*		..	....	.97
22....	Lacaille 8760	21 11.4	—39 15	6.6	M1	...	...	..	....	3.46
23....	Krüger 60	22 24.5	+57 12	9.8	M4	11.3	M6	..	....	.87
24....	Kapteyn's star	5 7.7	—44 59	8.8	M0	...	...	..	....	8.79
25....	van Maanen's star	0 43.9	+ 4 55	12.3	F0	...	...	..	....	2.98
26....	Groombridge 1618	10 5.3	+49 58	6.8	K6	...	...	..	....	1.45
27....	Wolf 424	12 28.4	+ 9 34	12.6	(M5e)	12.6	(M5e)	..	....	1.87
28....	CD—46°11540	17 21.1	—46 47	9.4	M3	...	...	..	....	1.15
29....	AOe 17415-6	17 37.0	+68 26	9.1	M4	...	...	..	....	1.31
30....	Ross 780	22 47.9	—14 47	10.3	M5	...	...	..	....	1.12
31....	CD—44°11909	17 29.8	—44 14	10.0	M5	...	...	..	....	1.14
32....	BD+20°2465	10 14.2	+20 22	9.5	M3e	*		..	....	.49
33....	CD—37°15492	23 59.5	—37 51	8.3	M3	...	...	..	....	6.09
34....	CD—49°13515	21 26.9	—49 26	8.6	M3	...	...	..	....	.78
35....	Altair	19 45.9	+ 8 36	0.9	A5	...	...	..	....	.66
36....	BD+43°4305	22 42.5	+43 48	10.2	M5e	...	...	..	....	.84
37....	o2 Eridani	4 10.7	— 7 49	4.5	G5	9.2	B9	10.7	M4e	4.08
38....	AC+79°3888	11 41.3	+79 14	11.0	M4	...	...	..	....	.87
39....	70 Ophiuchi	18 0.4	+ 2 31	4.3	K1	6.0	K5	..	....	1.13

* Unseen companion.

I

Five Parsecs

Position Angle	Radial Velocity km/sec	Parallax	Distance in Light-years	Absolute Visual Magnitude			Visual Luminosity			No.
				A	B	C	A	B	C	
...	...	.....	...	+ 5	...	...	1	...	......	 1
281°	— 22	″0.761	4.3	4.7	6.1	15.4	1.3	0.36	0.000069	 2
356	—110	0.530	6.1	13.3	...	...	0.00048	...	......	 3
187	— 87	0.411	7.9	10.7	...	...	0.0052	...	......	 4
235	— 90	0.408	8.0	16.6	...	...	0.000023	...	......	 5
204	— 8	0.381	8.6	1.3	10.0	...	30.	0.010	......	 6
106	...	0.350	9.3	13.7	...	...	0.00033	....	......	 7
176	...	0.317	10.3	14.7	...	...	0.00013	....	......	 8
46	...	0.315	10.3	14.8	...	...	0.00012	....	......	 9
271	+ 15	0.305	10.7	6.2	...	...	0.33	....	......	10
214	— 3	0.295	11.0	2.9	13.2	...	6.9	0.00052	......	11
52	— 63	0.294	11.1	7.9	8.6	...	0.069	0.036	......	12
151	...	0.292	11.2	13.4	...	...	0.00044	....	......	13
123	— 40	0.291	11.2	7.0	...	...	0.16	....	......	14
297	— 16	0.290	11.2	5.9	...	...	0.44	...	......	15
324	0	0.287	11.3	11.2	12.0	...	0.0033	0.0016	......	16
180	...	0.281	11.6	11.9	...	...	0.0017	....	......	17
82	+ 8	0.278	11.7	10.3	13.1	...	0.0076	0.00058	......	18
79	+ 10	0.271	12.0	9.6	...	...	0.014	....	......	19
171	+ 22	0.263	12.4	12.2	...	...	0.0013	....	......	20
131	...	0.260	12.5	13.1	...	...	0.00058	....	......	21
250	+ 22	0.260	12.5	8.7	...	...	0.33	....	......	22
247	— 24	0.256	12.7	11.8	13.3	...	0.0019	0.00048	......	23
131	+242	0.256	12.7	10.8	...	...	0.0048	....	......	24
155	+238	0.247	13.2	14.3	...	...	0.00019	....	......	25
249	— 27	0.231	14.1	8.6	...	...	0.036	....	......	26
278	...	0.230	14.2	14.4	14.4	...	0.00017	0.00017	......	27
138	...	0.225	14.5	11.2	...	...	0.0033	....	......	28
196	— 17	0.216	15.1	10.8	...	...	0.0048	....	......	29
120	...	0.213	15.3	11.9	...	...	0.0017	....	......	30
218	...	0.212	15.4	11.6	...	...	0.0023	....	......	31
264	+ 9	0.210	15.5	11.1	...	...	0.0036	....	......	32
112	+ 24	0.210	15.5	9.9	...	...	0.011	....	......	33
184	...	0.209	15.6	10.2	...	...	0.0083	....	......	34
54	— 26	0.208	15.7	2.5	...	...	10.	....	......	35
237	+ 2	0.208	15.7	11.8	...	...	0.0019	....	......	36
213	— 42	0.205	15.9	6.1	10.8	12.3	0.36	0.0048	0.0012	37
57	...	0.199	16.4	12.5	...	...	0.0010	....	......	38
167	— 7	0.197	16.5	5.8	7.5	...	0.48	0.10	......	39

NOTES TO TABLE I

1. For the binary stars the proper motions and radial velocities refer to the mass-centers; for α Centauri to the mass-center of *A* and *B*; for o² Eridani to the *A* component.
2. The position of α Centauri *C* (Proxima) is 14ʰ 22ᵐ.9, —62° 15′ (1900). Proxima is 2° 11′ from the center of mass of *A* and *B*, which corresponds to a projected distance of more than 10,000 astronomical units.
3. The separation of o² Eridani *B, C* from o² Eridani *A* is 83″; the relative proper motion indicates a period of the order of ten thousand years for the relative orbit of *BC* and *A*.
4. For Wolf 424 the components have been assigned the combined spectrum.

TABLE II

MASSES OF BINARY COMPONENTS

Name	*a*	Period	Masses	
α Centauri ....*A,B*	23.3 A.U	80 years	1.1 ⊙	0.9 ⊙
Sirius ....*A,B*	20.0	50	2.2	1.0
Procyon ....*A,B*	14.4	40.2	1.4	0.4
61 Cygni ....*A,B*	84.	720	0.6:	0.6:
Krüger 60 ....*A,B*	9.2	44.5	0.26	0.14
o² Eridani ....*B,C*	34.	248:	0.4	0.2
70 Ophiuchi ......*A,B*	23.3	87.8	0.90	0.73

a semi-axis major of 0.54 A.U. for the photocentric orbit, and a mass of 0.032 ⊙ for the companion. Strand[7] found one of the visual components of 61 Cygni to be an unresolved binary with a period of 4.9 years, a photocentric semi-axis major of 0.068 A.U., and a mass of only 0.016 ⊙ for the companion.[8] The

[7] *Pub. A.S.P.*, **55**, 29, 1942; *Proc. Amer. Phil. Soc.*, **86** (No. 3), 364, 1943.

[8] The perturbation with circular orbit and 17-year period assigned by Reuyl and Holmberg to 70 Ophiuchi (*Ap. J.*, **97**, 41, 1943) has not been confirmed in a subsequent, unpublished analysis by Strand, who finds that an orbit with period 3.6 years, eccentricity 0.2 and semi-axis major 0″.012 fits the observations better. The latter data give a semi-amplitude of less than 0″.010 in both right ascension and declination so that, as in the earlier visual history of 70 Ophiuchi, the reality of any perturbation must be questioned until considerably more photographic material is obtained.

"long" and "short" periods of 61 Cygni differ in order of length, so that as a first approximation the resultant orbital motion could be dissected into two Keplerian motions, as was that of the two visual triple systems α Centauri and o^2 Eridani.

Variable proper motions[9] have been discovered at the Sproul Observatory for Barnard's star (1939), for Lalande 21185 (1941), and[4] for BD+5°1668 (1943). Provisional orbits for the first two of these stars give periods of somewhat more than a year, photocentric semi-axes major of somewhat more than 0.1 A.U., and for the unseen companions minimum masses of about 0.06 ☉.

Strand's value for the mass of the invisible companion of 61 Cygni indicates that the companion may be too feeble to be seen by its own radiation even if no glare of the primary were present.[10,11] The companions of Ross 614, Barnard's star, and Lalande 21185, are probably not truly dark or invisible, but simply unseen.

Some of the well-known statistical properties of visible stars are represented in this small but accurately studied sample of the stellar system. With the exception of the three white dwarfs and two stars with unknown spectra, the remaining stars reveal a remarkable sharpness of the main sequence (Fig. 1), considering the presence of observational errors and unresolved binaries. The predominance of red dwarfs is obvious. The frequency distribution of absolute magnitudes is, of course, affected by incompleteness of the data, but an increase up to at least about $M = +12.5$ (Table III, and Fig. 2) is indicated. The 15 available masses exhibit clearly the mass-luminosity relation with the conspicuous exception of Sirius *B* and Procyon *B* (Fig. 3). Only four of these stars exceed the sun in luminosity. The star of lowest known luminosity, the distant proper-motion companion to BD+4°4048, recently discovered by van Biesbroeck,[12] is, however, outside the five-parsec limit. The position

[9] *Proc. Amer. Phil. Soc.*, **88** (No. 5), 372, 1944.

[10] *Pub. A.S.P.*, **55**, 79, 1943; *A.J.*, **51**, 13, 1944.

[11] *Sky and Telescope*, **4**, 5, 1944.

[12] *A.J.*, **51**, 61, 1944.

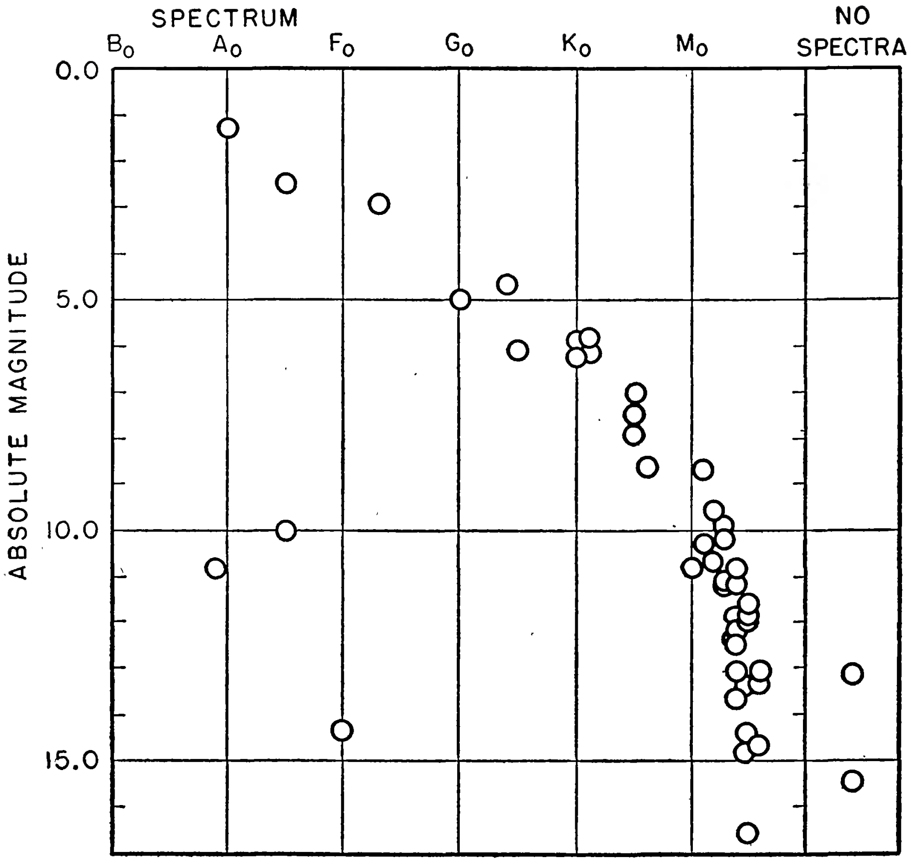

FIG. 1.—Russell diagram for stars nearer than five parsecs

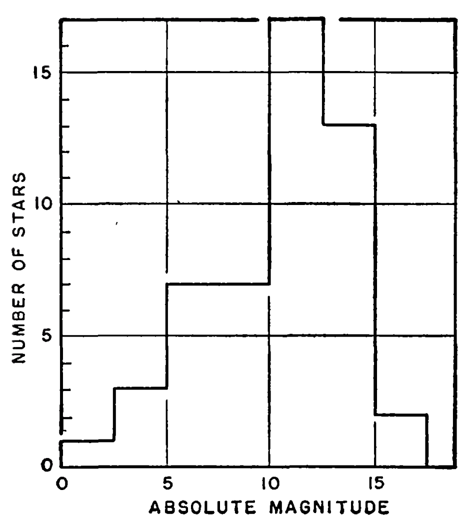

FIG. 2.—Frequency distribution of absolute magnitudes

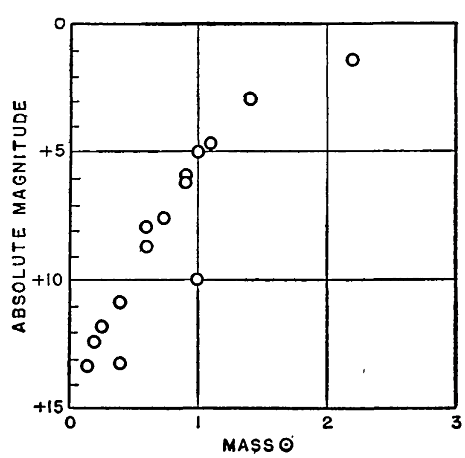

FIG. 3.—Mass-luminosity relation

of the star is α 19^h 12^m.1, δ + 5° 0′; the apparent magnitude is 18, the parallax, 0″.170. Its absolute magnitude is +19.2, only 1/500,000 of the sun's luminosity, or ten times as faint as Wolf 359, the faintest star nearer than 5 parsecs.

TABLE III

DISTRIBUTION OF ABSOLUTE MAGNITUDES

Absolute Visual Magnitude	No. of Stars
+1.3 to +2.4	1
2.5 to 4.9	3
5.0 to 7.4	7
7.5 to 9.9	7
10.0 to 12.4	17
12.5 to 14.9	13
15.0 to 16.6	2

Attention is drawn to the abundance of double (and triple) objects. Excluding the sun with its planetary companions, the five nearest objects average two component stars each; at greater distances this high average is not maintained, which, however, may be partly a matter of resolution. Further discovery of astrometric binaries with unseen companions is expected through the systematic studies under way at different observatories.[11] The status of the solar system may then be further clarified and may well appear even more exceptional, thus influencing our ideas about the evolution of the solar system.[9] The recognition of unresolved binaries among stars at present considered single will aid in improving the values of their parallaxes, which may have been systematically distorted by partial absorption of the photocentric orbital motion.[13]

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[13] *A.J.*, **51**, 70, 1944.