Survey of Long-term Stellar Variabilities

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Abstract

The comparison of visual magnitudes of stars recorded in historical star catalogues is expected to yield information about their long-term magnitude variations over ~2000 years. Considering the epoch when the first systematic and accurate observations of fixed stars were catalogued, stars with long-term of the order of 100, 1000 or more years variability have not been found yet. However it is still possible that there are stars with longer timescales than 100 years variability.

First, by comparison of seven old catalogues including 2123 sampled stars, the independence of stellar magnitude catalogues is demonstrated. Furthermore, comparing them with a modern star catalogue, one can see that the magnitude differences show a Gaussian distribution. If they are sufficiently larger than the deduced standard deviations, magnitude variations between catalogues can be considered real. Essentially, the stellar magnitudes compiled in old works can be used as scientific data within the average intrinsic uncertainty. These seven old catalogues can be used as data for the survey of the long-term variability of stars.

Second, we investigate magnitude systems in these historical star catalogues. We put all data set on Pogson's logarithmic and the power-law scale suggested by those believed that human's sensitivities were on a power-law scale, and verify that magnitude systems fit logarithmic scale and that light ratios also correspond to that of Pogson.

Third, we find that through 2123 data sets of stellar magnitude, most of stars recorded in old star catalogues show little or no variation. The number of stars with magnitude variation larger than 3 mag during these ~ 2000 years reaches 8. Especially, α Sgr shows the largest variation of 3.91 mag. Comparing the magnitude of this object with those of stars in the neighborhood, nearby stars show very small or no variation. Therefore, it could be considered that the magnitude of α Sgr has not changed due to the observational condition. There is no reason to change the magnitude because this object is one of the main-sequence stars on the H-R diagram and not consists of binary system. We carried out to find a candidate of long-term variability stars undiscovered and whose mechanism has not been explained.

Keywords: variable stars, transient objects, historical star catalogues, stellar magnitude, photometry

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1. General introduction

Approximately 100 years have passed since the first systematic and accurate observations of fixed stars were catalogued, i.e. stars with long-term of the order of 100, 1000 or more years variability have not been found yet. However, it is still possible that there are stars with longer timescales than 100 years variability. The goal of this study is to study such long-term variable stars and find the nature of their magnitude variations through the survey of stellar magnitudes in old star catalogues. In this study, we treat variable stars, including transient objects (supernovae, novae, γ-ray bursts (GRB)).

In GCVS (General Catalogue of Variable Stars), individual objects discovered and named as variable stars by 1981 amount to 28435. These stars are classified into seven types found in Table 1. This catalogue contains non-variable (misidentified) stars and unique variable stars outside the range of the classifications. Some variable stars belong to several types of light variability simultaneously. (By July 2001, variable stars recorded in GCVS amount to 37391.)

Long-term variabilities with large amplitudes can occur through several mechanisms; eclipsing binaries, pulsating variables, etc.

Currently, the longest period of a known eclipsing binary is 27.1 years of ε Aur, varying between 3.37–3.91 magnitudes. This variance can be recognized by naked-eye observations. One would assume that the duration of the minimum should be longer for a system with a longer orbital period (ε Aur stays at minimum during ~ 500 days), thus the variability of such

Table 1 GCVS variability types.

GCVS variability types (total number)	sample type (total number)
(1) eruptive (2778)	GCAS: Eruptive irregular variables of the γ Cas-type (120)
	SDOR: Variables of the S Dor-type (15)
(2) pulsating (18896)	DCEP: Classical cepheids or δ Cep-type variables (640)
	M: Mira (o Cet)-type variables (5829)
	SR: Semiregular variables (3385)
(3) rotating (260)	PSR: Optically variable pulsars (CM Tau) (1)
(4) cataclysmic (explosive and novalike) variables (624)	N: Novae (200)
	SN: Supernovae (B Cas, CM Tau) (7)
(5) eclipsing binary systems (5022)	EA: Algol (β Per)-type eclipsing systems (3053)
	EB: β Lyr-type eclipsing systems (587)
	EW: W UMa-type eclipsing variables (562)
(6) intense variable X-ray sources (44)	XB: X-ray bursters (5)
(7) other symbols (939)	BLLAC: Extragalactic BL Lac-type objects (4)

a system can be overlooked if the observation was made within a short period. Essentially, it means that the photometric observations for some catalogues may have been performed during an eclipse where the recorded magnitudes could be at the minimum, while other observations show the magnitudes out of an eclipse.

Except within the eclipsing binaries, variabilities with timescales longer than those of Mira type pulsating variables (~1 year) have rarely been observed. The timescale of Mira type variables is dominated by the stellar dynamic timescale, which cannot be longer than several years. On the other hand, some variabilities with timescales longer than 1 year may have been recorded within the history of mankind. The helium flash at the core of an intermediate mass star is one possible example, which leads a star from the red giant branch to the horizontal branch. Another example is a final helium shell flash and a thermal pulse stage, as in FG Sge (Herbig and Boyarchuk 1968) or V4334 Sgr =‘Sakurai’s Object’ (Duerbeck et al. 1997). ‘Sakurai’s Object’ was discovered by Yukio Sakurai, Otsuka-cho, Mito, Ibaragi-ken. The photograph taken on February 20.806 1996 UT shows the star as red in color and of mag 11.4. Patrol films taken by Sakurai during 1993–1994 show no candidate at this location, but the star is visible on films beginning in January 1995 (when it was 12.5 mag) and continuing through May, August–October, and again in 1996 January–February, the star slowly brightening over the past year (Nakano et al. 1996). The slow brightness evolution, and the C-rich and H-poor spectrum, make this object the first candidate for a star undergoing its final helium flash (post-AGB (asymptotic giant branch) star) since the eruption of V605 Aql in 1919 (Duerbeck et al. 1996).

Other violent variables can be observed, such as S Dor type variables (P Cyg, η Car) or ones with uncertain mechanisms like V838 Mon. One such variable is the widely recognized δ Sco, which has brightened up unexpectedly from 2.3 mag to about 1.8 mag since July 2000. Previously known as a stable normal B star, this star is now classified as an eruptive irregular variable of the γ Cas type. This type of star is a rapidly rotating B III-IVe star with mass outflow from its equatorial zone. The formation of equatorial rings or disks is often accompanied by temporal fading or brightening. Light amplitudes may reach 1.5 mag in V. (Otero et al. 2001; Fabregat et al. 2000). The variability of δ Sco was not expected.

Sudden magnitude changes of giant stars belonging to Semi-Regular type have also been detected. ε Peg usually varies in the range 2.29–2.44 mag in V. On September 26/27, 1972 in the interval 23h58m–00h02m UT it was bright (0.7 mag in V), then at 00h09m UT decreased to 2.4 mag in V (Wood 1972). On November 5, 1847, the star was 3.5 mag, then the brightness increased but on November 6, it was still fainter than normal (Schmidt 1857). Likewise, ρ Cas usually varies within the limits 4.4–5.2 mag in V. In November 1945, the peculiar decrease of brightness began lasting for 165 days and in September 1946 the star reached the middle of the deepest minimum lasting for 320 days. Then the brightness began to increase symmetrically, and by July 1947 the star attained its normal brightness (Gaposchkin 1949).

As in these stars mentioned above, there may be many magnitude variations hitherto unknown.

Otherwise, these are variable stars showing outbursts caused by thermonuclear burst processes in their surface layers (novae) or deep in their interiors (supernovae). Historically, nova was the name used for an apparently new star; eventually it turned out to be a misnomer, novae being (faint) stars that brighten suddenly by many orders of magnitude. So as supernovae, but on a much larger scale. Not until the 1930s, supernovae were recognized as a separate class of objects within novae in general. Classical novae (see Table 2) are close binary systems with orbital periods from 0.05 to 230 days. One of the components of these systems is an accreting white dwarf that suddenly, during a time interval from one to several dozen or several hundred days, increases its brightness by 7–19 mag in V ($-6 \sim -10$ in M_V), then returns gradually to its former brightness over several months, years, or decades. Supernovae are stellar explosions as a whole, and flare with $M_V = -14 \sim -20$ at maximum, then fade slowly.

Through our research, we expect that our survey catches such astronomical phenomena and that our study may contribute to stellar physics.

In order to inspect stellar magnitudes of earlier eras, we referred to historical star catalogues kept in libraries all over the world. Currently the following seven catalogues have been selected as reliable ones:

1. *Almagest* (Ptolemy AD127–141)
2. *Kitāb Ṣuwar al-Kawākib* (al-Ṣūfī 986)
3. *Ulugh Beg's Catalogue of stars* (1437)
4. *Astronomiae Instauratae Progymnasmata* (Brahe 1602)
5. *Uranometria* (Bayer 1603)
6. *Historia Coelestis Britannica* (Flamsteed 1725)
7. *Uranometria Nova* (Argelander 1843).

The characteristics of each star catalogue are described in Sect. 2.3.

Table 2 Selected list of classical novae.

Name	(alternate name)	m_{max}	m_{min}
GK Per	(N Per 1901)	0.2v*	13.0v
T Aur	(N Aur 1891)	4.1B	14.9B
RR Pic	(N Pic 1925)	1.2v	12.3v
CP Pup	(N Pup 1942)	0.2v	15.0v
GQ Mus	(N Mus 1983)	7.2v	17.5v
DQ Her	(N Her 1934)	1.3v	14.7v
FH Ser	(N Ser 1970)	4.4v	16.1v
V693 CrA	(N CrA 1981)	6.5v	> 19v
V603 Aql	(N Aql 1918)	−1.4v	11.6v
V1370 Aql	(N Aql 1982)	7.5p	20.0p
PW Vul	(N Vul 1984 No. 1)	6.4v	17.0v
HR Del	(N Del 1967)	3.3v	12.1v
V1500 Cyg	(N Cyg 1975)	2.0B	16.3B
V1668 Cyg	(N Cyg 1978)	6.0v	20:
OS And	(N And 1986)	6.2v	17.8B

* B, v, and p are the blue, visual, and photographic magnitudes.

This study is partly based on the master thesis of the author (Fujiwara 2000). Our study addresses some aspects of historical star catalogues that could have useful applications in studies of long-term stellar variability and nova or supernova events. For variable stars, we generally do not have a long enough time base to discover very long-term variabilities. If we wish to investigate such a possibility, then we would be obliged to use the fragile evidence from the few early measurements of stellar magnitudes. Systematic quantitative studies of these catalogues are rare and the results of this study are found to be interesting. The survey of long-term stellar variabilities using historical star catalogues is very rare, however, it is very important for astrophysics. On one hand, some astronomers studying variable stars use historical records to investigate the magnitude in the periods of their target star. For example, Hearnshaw (1999) tries to detect AGB stars using '*Almagest*'. Another example is a investigation of Mira type variables, using one of the works of Hevelius (1690) and star catalogues of the 19th and the 20th centuries (Zijlstra et al. 2002). However, each of them refers to only one or a few latter catalogues. On the other hand, there are several works, in which magnitude data are compared with other historical records (al-Bīrūnī 1030; Bevis 1750; Schjellerup 1874; etc.). However, in these works, they considered magnitude differences not as variations but as discrepancies. Consequently, their studies did not lead to an astronomical research of variable stars. In this point, our study has potentialities to discover undiscovered phenomena.

In this paper, we present a general history of magnitude records and characteristics of old catalogues in Sect. 2. Magnitude data and their analysis are found in Sect. 3. In Sect. 4, we show the following results. Before we could use the above studies, we had to check their reliability as scientific data. First, we analyzed this problem on the basis of a statistical test for the distribution of magnitude differences taken from each pair of these studies. Second, as an additional check on the reliability of the seven historical catalogues, we also compared the data compiled in them with modern data taken from the '*Sky Catalogue 2000.0*' (Hirshfeld et al. 1991). Third, we present the results of our study of magnitude systems in old star catalogues. Forth, we show the candidates of stars with long-term variability and their astronomical basic data, and discuss the cause of magnitude variation. The conclusions are summarized in Sect. 5.

2. Astronomical photometry

2.1 Historical review on astronomical phenomena records

Many ancient civilizations have left evidence of interest in astronomical events. Such interests were motivated by the numerous concerns of daily life. Since the long-ago, people observed stars and recorded celestial phenomena and their nature. They were interested in many parts; calendar, motions of planets (including the Sun and the Moon), mathematical astronomy, astrology, cosmology, etc. Relative to fixed stars, they accrued data, especially on the positions of celestial bodies (the Sun, the Moon, planets and fixed stars) with ecliptic coordinates (ecliptic longitude and ecliptic latitude) for the ancient times or with equatorial coordinates (right ascension and declination) for the modern times. Concerning stellar magnitudes, they believed to be dependent on the size of stars and made little account. In ancient Chinese records, stellar magnitudes were not digitized but were shown in star charts as a big star (indicates a bright star) or a small star (indicates a dim star). Originally, ancient people never conceived that stellar magnitudes would change and never had the concept of variable stars. Therefore, the sudden appearances of supernova or nova astonished them. These astronomical phenomena occurred suddenly and light amplitudes are much larger than general variables. Therefore, such phenomena have been recorded in many works since ancient times. Actually, as shown in Table 3, there are many records on historical supernovae (Green & Stephonson 2003).

One of these records is '*Meigetsuki*'（明月記）written by Teika Fujiwara (*b.* 1162; *d.* 1241), well-known in Japan. He noted that 「天喜二年四月中旬以降、丑時客星出觜参度、見東方、孛天関星、大如歳星」. (Currently, '四' is recognized as a mistake for '五' in general.) It means that on 1–3 a.m. 19–28 June, 1054, a guest star appeared for the direction of Orion in the east and it flared near the Tenseki (ζ Tau) and it was as large bright as Jupiter. Unfortunately, he did not observe it directly but noted the record of predecessor probably lost over the years. Currently, this supernova is identified as SN1054, whose remnant (SNR) is well known as Crab nebula (M1, NGC1952). The supernova was noted on July 4, 1054 A.D. by Chinese astronomers, and was about four times brighter than Venus, or about −6 mag. According to the historical records, it was visible in daylight for 23 days, and 653 days to the naked eye in the night sky. It was probably also recorded by Anasazi Indian artists (in present-day Arizona and New Mexico), as findings in Navajo Canyon and White Mesa (both Arizona) as well as in the Chaco Canyon National Park (New Mexico) indicate. The images depict a large star adjacent to a crescent moon. Astronomers have calculated that on the morning of July 5, 1054 that the supernova was two degrees south of the Moon. In 1939, the astronomer John Duncan

Table 3 Summary of the historical supernovae.

date	length of visibility	remnant	historical records				
			Chinese	Japanese	Korean	Arabic	European
BC14c.?	—	2C G353+16 ?	one?	—	—	—	—
AD185	8 or 20 months	SNR G315.4−2.3 ?	one	—	—	—	—
AD369?	5 months	—	one	—	—	—	—
AD386?	3 months	SNR G11.2−0.3 ?	one	—	—	—	—
AD393	8 months	RX G347.5−0.5	one	—	—	—	—
AD837?	22 days ?	IC 443 ?	one?	—	—	—	—
AD891?	—	—	—	one?	—	—	—
AD1006	3 years	SNR G327.6 + 14.6	many	many	—	few	two
AD1054	21 months	Crab Nebula	many	few	—	one	—
AD1181	6 months	3C 58	few	few	—	—	—
AD1408?	—	SNR G69.0+2.7 ?	few	two	—	—	—
AD1572	18 months	SNR G120.1 + 2.1	few	—	two	—	many
AD1592?	15 months?	—	—	—	one?	—	—
AD1604	12 months	SNR G4.5 + 6.8	few	—	many	—	many
AD1680?	—	Cas A	—	—	—	—	one?

suggested that the Crab Nebula was expanding at the rate consistent with a point source origin of about 766 years earlier. A subsequent astronomer, William Miller, calculated that the Crab Nebula supernova would have been visible just before dawn on July 5, 1054, which matches the Chinese observations, and is consistent with the Native American rock art. Miller's paper of 1955 cited two examples of Arizonan rock art depicting the SN1054.

On November 11, 1572, a nova appeared in the constellation of Cassiopeia and Danish astronomer Tycho Brahe took many measurements of the star. Nevertheless, Tycho had not been the first to discover this 'new' star; it was probably first seen by W. Schuler on November 6, 1572. Tycho found it at about as brilliant as Jupiter, and it became soon equal to Venus. For about two weeks, the star could be seen in daylight. At the end of November, it began to fade and change color, from bright white over yellow and orange to faint reddish light, finally fading away from visibility in March, 1574, having been visible to the naked eye for about 16 months. This nova (SN1572) is called 'Tycho's nova', as well as B Cas.

In star chart of Flamsteed, these is a star not known today. In 1680, he recorded a 6th magnitude star '3 Cas', to the west of τ Cas, fairly close to the present site of Cassiopeia A (Cas A). However, the discrepancy in the positions of 3 Cas and Cas A, about $10'$, is much larger than Flamsteed's typical measurement error. 'Did Flamsteed see this supernova or not?', it is still a puzzle.

Table 4 The first known variable stars (except for Novae and Supernovae).

star	type	epoch	discoverer
o Cet (Mira)	M	1596	David Fabricius
P Cyg	SDOR	1600	Willem Janszoom Blaeu
β Per (Algol)	EA	1669	Geminiano Montanari
η Car	SDOR	1677	Edmond Halley
χ Cyg	M	1687	Gottfried Kirch
R Hya	M	1704	Giacomo Filippo Maraldi
R Leo	M	1782	J. A. Koch
η Aql	DCEP	1784	Edward Pigott
β Lyr	EB	1784	John Goodricke
δ Cep	DCEP	1784	John Goodricke
i Boo	EW	1785	William Herschel
α Her	SR	1795	William Herschel
R CrB	RCB	1795	Edward Pigott
R Sct	RV	1795	Edward Pigott
R Vir	M	1809	Harding
R Aqr	M	1810	Harding
ε Aur	EA	1821	Fritsch
R Ser	M	1826	Harding
S Ser	M	1828	Harding
R Cnc	M	1829	Schwerd
α Ori (Betelgeuse)	SR	1836	John Herschel

Table 5 The number of calalogued variable stars.

epoch	compiler	number
1715	Halley	6
1786	Pigott	12⋆
1850	Argelander	24
1854	Pogson	53
1865	Chambers	113
1888	Gore	243
1903	Pickering	701
1915	Müller & Hartwig	1687
1930	Prager	4581
1947	Kukarkin	14708
1981	Kholopov (GCVS)	28435
2001	Kholopov (GCVS)	37381

⋆ including novae

As shown in Table 3, supernovae were sometimes recorded not only in star catalogues but in literatures and monuments in all cultures as well as records of solar eclipses. Contrarily, the recognition of variable stars is much later. Because medieval western astronomers looked at fixed stars as eternal and invariable entities. Soon after the appearance of SN1572 (Tycho's Nova), the discovery of variable stars began. The first star recognized as a variable was Mira (*o* Cet) in 1596. (The name 'Mira' was given by Hevelius in the 17th century.) Currently this star is well known as a periodic variable (typical pulsating variable), however, the periodicity was discovered later in 1638 by Holwarda. In 1715, Edmond Halley published a list containing all 6 variables known at that time. In 1781–2, when William Herschel discovered Uranus and published a catalogue of 269 double stars. In 1784, Charles Messier published his catalogue of 103 nebulae and star clusters (known as 'Messier's catalogue') in '*Connaissance des Temps*'. (Subsequently 7 objects were added, however M47, M48, M91 and M102 were not fully identified.) On that time, still only ten variables were known, four of them are Mira type periodic. The research of variable stars became a more serious science not before 1844. After the calling for their observation, and the publication of the list of these variables by Argelander, they started to be known (see Table 5).

2.2 Naked-eye visual magnitude estimates and their systems

The concept of magnitudes was introduced by Hipparchus in the 2nd century B.C. (cf. Hearnshaw 1996). Hipparchus compiled his catalogue of 850 stars with the ecliptical coordinates and the visual magnitudes. This work was triggered by the discovery and the observation of a nova (not yet explained) in the constellation Scorpius in 134 B.C. He started to record the coordinates and magnitudes of fixed stars in order to aid discoveries of such objects, and to record the brightness. He defined the brightest 20 stars as 1st magnitude. Currently, stars of 1st magnitude amount to 21 as shown in Table 6. Polaris (α UMi) and stars of the Great Dipper in

Ursa Major were defined as 2nd magnitude (see Table 7) and stars at the observable limit of the naked eye as 6th magnitude.

The work of Hipparchus was lost over the years, however, Hipparchus' magnitude system came down through subsequent star catalogues ('*Almagest*' etc.).

In the nineteenth century, astronomers tried to define the magnitude system more precisely and quantitatively, based on simple arbitrary visual estimates. Many astronomers (W. and J. Herschel etc.) had already investigated the magnitude-intensity relationship and deduced the

Table 6 Stars of 1st and brighter magnitude (in order of right ascension).

star	name	V
α Eri	Achernar	0.50
α Tau	Aldebaran	0.85
β Ori	Rigel	0.12
α Aur	Capella	0.08
α Ori	Betelgeuse	0.58
α Car	Canopus	− 0.72
α CMa	Sirius	− 1.47
α CMi	Procyon	0.34
β Gem	Pollux	1.15
α Leo	Regulus	1.35
α Cru		0.81
β Cru		1.30
α Vir	Spica	1.04
β Cen		0.60
α Boo	Arcturus	− 0.04
α Cen		− 0.1
α Sco	Antares	1.09
α Lyr	Vega	0.03
α Aql	Altair	0.77
α Cyg	Deneb	1.25
α PsA	Fomalhaut	1.16

Table 7 Magnitude of Polaris and the Great Dipper.

star	V
α UMi	2.005
α UMa	1.79
β UMa	2.346
γ UMa	2.427
δ UMa	3.304
ε UMa	1.760
ζ UMa	2.06 (ζ1: 2.27, ζ2: 3.95)
η UMa	1.852

logarithmic form. They determined and proposed the light ratio R shown in Table 8. Based on Ptolemy's star catalogue '*Almagest*', Pogson (1856) proposed adopting a light ratio $R = 2.512$ for two stars that differ in brightness by one magnitude, defining the magnitude as

$$m = -\frac{1}{\log R} \log I. \qquad (2.\ 1)$$

In this formula, m signifies the apparent magnitude and I signifies the light intensity. In the case of $R = 2.512$, this formula could be transformed into

$$m = -2.5 \log I. \qquad (2.\ 2)$$

This definition is well-known as Pogson scale and is still used in stellar photometry.

In the 1960s, psychophysists propounded that the response of human's sensitivity would be a power law (Stevens 1961). Referring to this theory, Schulman & Cox (1997) suggested that visual magnitude estimates were much better fit to a power law. Equally, the eye's response to the light is a power law, and therefore visual magnitude estimates disagreed with the logarithmic system.

Independently, Hearnshaw examined data in '*Almagest*', and showed that the magnitudes fitted to the logarithmic scale. The light ratio of '*Almagest*' is, however, 3.26 (Hearnshaw 1996) and derived as 3.42 (Hearnshaw 1999) being far larger than that of Pogson's.

In order to verify that visual magnitude estimates fit either a logarithm or a power law, we intend to investigate the magnitude systems in old star catalogues (see 4.3). In all of the star catalogues mentioned below, stellar magnitudes were estimated with the naked eye and were

Table 8 Determinations for the light ratio R.

epoch	author	R	remarks
1829	J. Herschel	2.551	
		2.00	adopted for telescopic stars
1836	C. A. von Steinheil	2.831	
1837	F. G.W. Struve	2.890	
		4.00	adopted for telescopic stars
1851	S. Stampfer	2.494	
1853	M. J. Johnson	2.358	78 stars of 4 to 10 mag.
1856	Pogson	2.512	Pogson's proposal
1857	R. C. Carrington	2.747	
1860	G. T. Fechner	2.241	
1862	P. L. Seidel	2.8606	
1862	K. Bruhns	2.718	reported by Seidel (1862)
1865	F. Zöllner	2.755	293 stars of 1 to 6 mag.
1866	P. L. Seidel &	2.203	for bright stars of 2 to 4 mag.
	E. Leonhard	2.857	for fainter stars to 6 mag.
1870	P. G. Rosén	2.470	110 stars in '*Bonner Durchmusterrung*' (BD) of 5 to 9.5 mag.
1878	C. S. Peirce	2.339	recalculation of Rosén
1888	E. Lindemann	2.421	BD stars of 3 to 9 mag.

classified by 1st to 6th based on the Hipparchus' system. In addition, for refinement, observers used plus or minus signs to indicate 'a little brighter' or 'a little dimmer', respectively. To quantify these magnitude descriptions, we subtracted or added 0.33 according to the plus or minus sign, respectively. For example, we assigned 2.67 for 3+ and 3.33 for 3−.

2.3 Characteristics of old catalogues

2.3.1 *Almagest*

'*Almagest*' provides the earliest quantitative information on the brightness of the stars. It was written by Ptolemy (or Claudius Ptolemaeus) (*b. ca.* A.D. 100; *d. ca.* A.D. 170) in the 2nd century AD. The place of Ptolemy's observation is considered to be Alexandria, and there is no reason to suppose that he ever lived anywhere else. His name 'Ptolemaeus' indicates that he was an inhabitant of Egypt, descended from Greek or Hellenized forebears, while 'Claudius' shows that he possessed Roman citizenship. Ptolemy's chief work in astronomy, and the book on which his later reputation mainly rests, is the '*Almagest*', in thirteen books. The Greek title of '*Almagest*' is μαθηματικὴ σύνταξις, which means 'mathematical (astronomical in this case) compilation'. In later antiquity it came to be known informally as ἡ μεγάλη σύνταξις or ἡ μεγίστη σύνταξις (the great or greatest compilation), perhaps in contrast with a collection of earlier Greek works on elementary astronomy called ὁ μικρὸς ἀστρονομούμενος (the small astronomical collection). The translators into Arabic transformed ἡ μεγίστη into 'al-majistī', and this became 'almagesti' or 'almagestum' in the medieval Latin translations.

In order to appreciate Ptolemy's achievement in the '*Almagest*', we ought to know how far Greek astronomy had advanced before his time. Unfortunately the most significant works of his predecessors have not survived, and the earlier history has to be reconstructed almost entirely from secondary source (chiefly the '*Almagest*' itself). It is a manual covering the whole of mathematical astronomy as the ancients conceived it. Astronomical observations were being made in the Greek world from the late fifth century B.C. By the early third century, however, observations to determine the positions of fixed stars and to observe occultations were few and unsystematic. The first Greek who established Greek astronomy as a quantitative science is Hipparchus (active from *ca*. 150 to 127 B.C.). He used Babylonian eclipse records and his own systematic observations to construct an epicyclic theory of the sun and moon. He measured the lunar parallax and evolved the first practical method of determining the distances of sun and moon. Greek astronomy had evolved a geometric kinematic model of solar and lunar motion that successfully represented the phenomena, at least as far as the calculation of eclipses was concerned, but had produced only unsatisfactory planetary models. It could show only existing theories not satisfied the observations. From the point of view of physics, it was not a science at all: such physical theories as were enunciated were mere speculation.

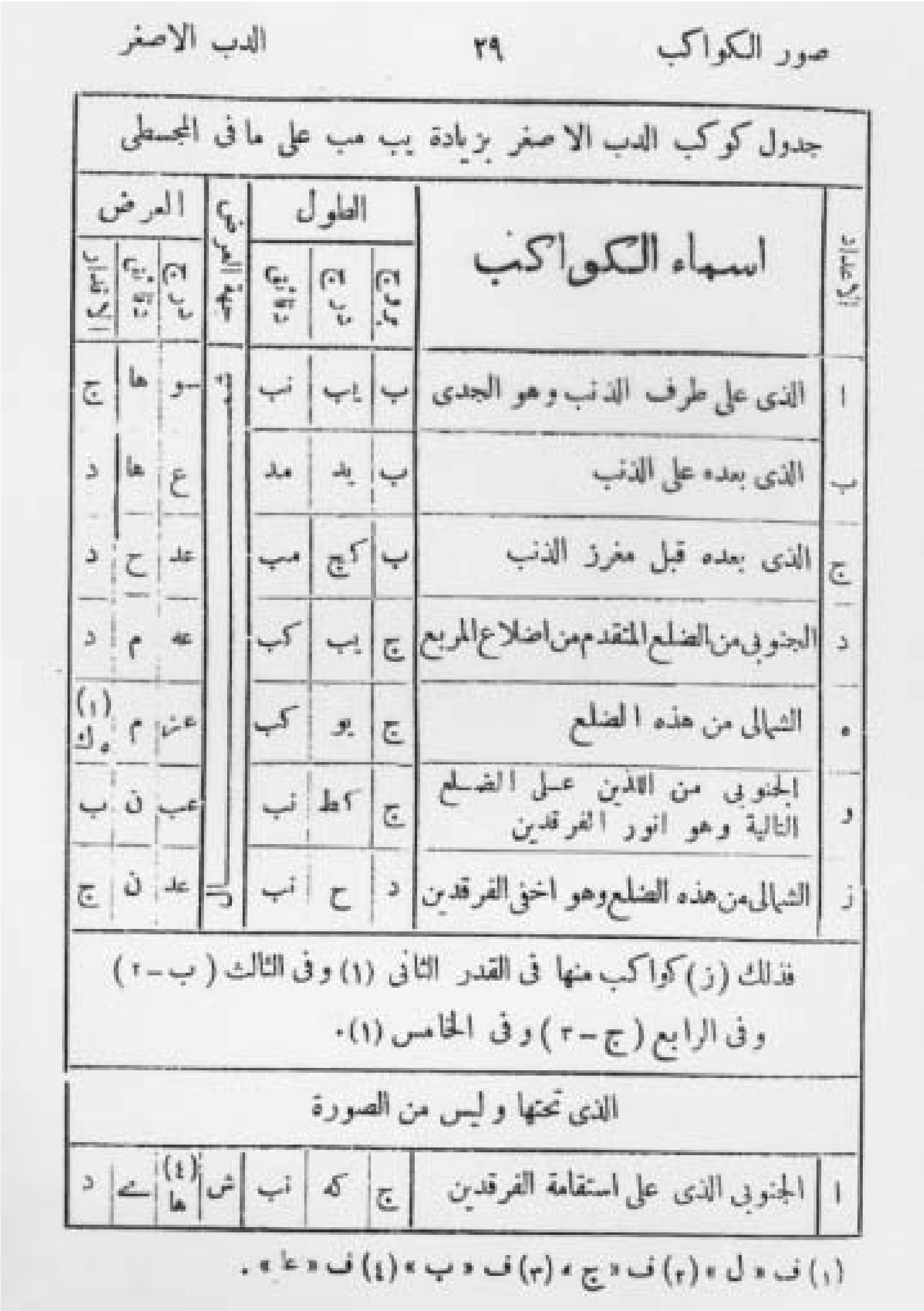
The order of treatment of topics in the '*Almagest*' is completely logical. In Book I, after a brief treatment of the nature of the universe, Ptolemy developed the trigonometrical theory. In Book II, he discussed those aspects of spherical astronomy. Book III is devoted to the theory of the sun. This is a necessary preliminary for the treatment of the moon in Book IV, since the use of lunar eclipses there depended on one's ability to calculate the solar position. Book V treated the advanced lunar theory, which was a refinement of that in Book IV, and also lunar and solar parallax. Book VI was on eclipses, and thus required knowledge of both solar and lunar theory, and also of parallax. Book VII and VIII treated the fixed stars: it was necessary to establish the coordinates of ecliptic stars to observe planetary positions. Ptolemy compared his own observations with those of Hipparchus and earlier Greeks to show that the relative positions of the fixed stars had not changed and that the sphere of the fixed stars moved about the pole of the ecliptic from east to west 1° in 100 years with respect to the tropical points (the precession of the equinoxes). The bulk of these two books is composed of the star catalogue, a list of 1022 stars, arranged under 48 constellations, with the longitude, latitude and magnitude (from 1 to 6) of each. The last five books are devoted to planetary theory. Book IX–XI developed the theory of their longitudinal motion, Book XII treated retrogradations and greatest elongations, while Book XIII dealt with planetary latitude and those phenomena which were partially dependent on it.

The '*Almagest*' contains all the tables necessary for astronomical computations. In this study, we used only his star catalogue of the fixed stars (books VII and VIII). Ptolemy's original catalogue has not survived, but there are numerous manuscript copies from the 9th to 16th centuries. Intensive philological studies of '*Almagest*' were conducted by Kunitzsch (1986) and Toomer (1998). We used the star catalogues of these two works, and sampled visual magnitudes of 1022 stars of 48 constellations. Ptolemy's own recorded observations range from AD 127 to 141 and his catalogue epoch is about AD 137.

2.3.2 *Kitāb Ṣuwar al-Kawākib*

'*Kitāb Ṣuwar al-Kawākib*' ('*Ṣuwar al-Kawākib*' hereafter), which means Book on the constellations of the fixed stars, was written in Arabic in the 10th century by Abu'l-Ḥusayn 'Abd al-Raḥmān ibn 'Umar al-Ṣūfī (*b.* Rayy, Persia, 903; *d.* 986). al-Ṣūfī is most renowned for his observations and descriptions of the fixed stars. In this work, he presented the results of his investigations, in which he gives a critical revision of Ptolemy's star catalogue, adding the differing or additional results of his own observations. This work became a classic of Islamic astronomy for many centuries. In this work, the series of the 48 Ptolemaic constellations are presented in direction order: boreal constellations, twelve constellations on the ecliptic and austral constellations. He gave in his table of the stars, longitude, latitude, and magnitude for each star in 48 constellations. The epoch of his star table is 964. He added a constant of 12°42′ to Ptolemy's longitudes (adopting a precession of 1 degree in 66 years). However, the magnitudes represent the results of his own observations. This work is only significant work on stellar magnitudes between classical times and the Middle Ages, because most other medieval astronomers merely repeated the Ptolemaic star catalogues.

Since the art of printing was not yet developed in these days, our most serious concern was that a clerical error may have been made in the manuscript. In this study, we examined many manuscripts and literature relevant to this work. We mainly referred to '*Ṣuwar al-Kawākib*' (al-Ṣūfī 986a) edited in Hyderabad. This Arabic edition (353 pages) was collated with the oldest



صور الكواكب ٢٩ الدب الاصغر

جدول كوكب الدب الاصغر بزيادة يب مب على ما فى المجسطى

	اسماء الكواكب	الطول			[illegible]	العرض		
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ا	الذى على طرف الذنب وهو الجدى	ب	يب	نب	ش	سو	ها	ج
ب	الذى بعده على الذنب	ب	يد	مد		ع	ها	د
ج	الذى بعده قبل مغرز الذنب	ب	كج	مب		عد	ح	د
د	الجنوبى من الضلع المتقدم من اضلاع المربع	ج	يب	كب		عه	م	د
ه	الشمالى من هذه الضلع	ج	يو	كب		عز	م	(١) ه ك
و	الجنوبى من اللذين على الضلع التالية وهو انور الفرقدين	ج	كط	نب		عب	ن	ب
ز	الشمالى من هذه الضلع وهو اخفى الفرقدين	د	ح	نب		عد	ن	ج

فذلك (ز) كواكب منها فى القدر الثانى (١) وفى الثالث (ب – ٢)
وفى الرابع (ج – ٣) وفى الخامس (١).

الذى تحتها وليس من الصورة

ا	الجنوبى الذى على استقامة الفرقدين	ج	كه	نب	ش	(٤) ها	ے	د

(١) ف = ل ، (٢) ف = ج ، (٣) ف = ب ، (٤) ف = ع .

Photo. 1 *Kitāb Ṣuwar al-Kawākib*

extant manuscripts; [Marsh 144] Bodleian Library, Oxford (AD1009), [MS. 3493] Topkapu Sarai, Istanbul (AD1130), [MS. Rosse 1033] Vatican Library, Rome (AD1224), [MS. Landberg 71] The Berlin MS. (now in the University Library, Tubingen [Or. Quart 70]) (AD1232), [Or. 5323] British Museum, London (AD1258), [Bib. Nationale, Paris, Arabe 5036] Ulugh Beg Royal Library Codex (now preserved in the Bibliothèque Nationale de France, Paris) (AD1449) and [Sprenger 1854] Persian Translation (in the time of the Emperor Akbar 1556–1605).

Kunitzsch is a philological expert in the works of al-Ṣūfī. According to the advice of Kunitzsch, we referred to the works of al-Bīrūnī (1030) and Schjellerup (1874). In the work '*Al-Qānūn al-Mas'ūdī*', al-Bīrūnī gave magnitudes according to Ptolemy and to al-Ṣūfī in the star table with 1029 stars. Schjellerup was based on 2 manuscripts of '*Ṣuwar al-Kawākib*', of the Royal Library of Copenhagen [MS no. 83] (AD1601) and of Imperial Library of St. Petersburg (AD1015). We mainly adopted magnitude data in Hyderabad edition, however, in cases of discrepancy between catalogues, we gave them low weight as doubtful data.

2.3.3 *Ulugh Beg's Catalogue of Stars*

Ulugh Beg (*b.* Sulṭāniyya, Central Asia, 22 March 1394; *d.* near Samarkand, Central Asia [now Uzbek S. S. R.], 27 October 1449), which means 'great prince' was a title that replaced his original name, Muḥammad Taragay. At Samarkand in 1420 he founded a *madrasa*, or institution of higher learning, in which astronomy was the most important subject. An important result of the scientific work of Ulugh Beg and his school was the astronomical tables called the *Zīj* of Ulugh Beg or the *Zīj-i Gurgāni* (Guragon, the title of Genghis Khan's son-in-law, was also used by Ulugh Beg) (epoch 1437). This work was originally written in the Tadzhil language and the results of the observations including actual tables of calendar calculations, of trigonometry, and of the planets, as well as a star catalogue made at the Samarkand observatory.

Knobel (1917) revised '*Zīj-i Guragoni*' as '*Ulugh Beg's Catalogue of Stars*', using all the contemporary Persian manuscripts kept in Great Britain. We used in this study his French (partly English) edition.

2.3.4 *Astronomiae Instauratae Progymnasmata*

Tycho Brahe (*b.* Skåne, Denmark [now in Sweden], 14 December 1546; *d.* Prague, Czechoslovakia [Czech Republic], 24 October 1601) observed a supernova in Cassiopeia (Tycho's nova) in 1572. He measured the angular distance of the nova from nine stars in Cassiopeia and found no variation between observations. Tycho observed the star until the end of March 1574, when it ceased to be visible. His records of its variations in color and magnitude identify it as a supernova (in detail, see Sect. 2.1). He recorded it in two books (Brahe 1573, 1602). One of them, '*Astronomiae Instauratae Progymnasmata*' was summarized or criticized the work on the nova by others after his death in 1602. In this work, before the section on the nova, there are solar and lunar theories and a catalogue giving the positions and magnitudes of 777 fixed stars. The data in this catalogue are based on Tycho's own observations and are highly precise, especially in the determination of stellar positions (errors are within 1′). In this study, we used the reprinted edition of '*Astronomiae Instauratae Progymnasmata*'.

TYCHONIS BRAHE LIB. I.

STELLARVM INERRANTIVM

PLVRIMARVM ET PRAECIPVARVM,

IVXTA

AVCTORIS PROPRIAS ET ACCVRATAS

COELITVS RECENS DEDVCTAS

OBSERVATIONES,

CANONICA DETERMINATIO,

Ad Annum completum

1600.

PRIMO, DE STELLIS QVÆ APVD ZODIACVM CONSPICIVNTVR.

ARIES.

DENOMINATIO STELLARVM.	LONGITVDO. S.	G.	M.		LATITVDO. G.	M.		MAG.
Australis in præcedente cornu	♈	17	57		7	8½	B	4:
Borealis ac sequens in eodem cornu	♈	28	25		8	29	B	4:
Lucida in vertice capitis : Principalis	♉	2	6		9	57	B	3:
In rictu duarum borea	♉	2	34		7	23	B	6:
Quæ magis ad Austrum	♉	3	30		5	41½	B	6:
Quæ in ceruice	♈	27	57		5	24	B	5:
In renibus	♉	8	36		6	7	B	6:
Quæ in eductione caudæ	♉	12	57		4	8½	B	5
Præcedens trium in cauda	♉	15	25		1	46½	B	4
Media	♉	16	24		1	50	B	5
Vltima	♉	17	50½		2	36	B	6
In femore	♉	11	22		1	12	B	6
In poplite	♉	9	33		1	7	B	6
In genu sinistro *	♉	9	23		1	30	A	6
In genu dextro *	♉	7	52		0	39	A	6
Paruula in aluo *	♉	8	46		4	1	B	6

Quæ

Photo. 2 *Astronomiae Instauratae Progymnasmata*

2.3.5 *Uranometria*

Johanne Bayer (*b.* Rain, Germany, 1572; *d.* Augsburg, Germany, 7 March 1625) introduced a new method to name fixed stars in '*Uranometria*'. He was an amateur astronomer. On 1 September 1603, he dedicated his '*Uranometria*' to two leading citizens and the city council. The oldest surviving star catalogue, contained in Ptolemy's '*Almagest*', lists 48 constellations, with each star was identified usually by numbers and means of elaborate descriptions: for example, α UMi was described as 'the star on the end of the tail of the Little Bear'. This was often cumbersome and did not always direct every observer to the same star. Therefore, Bayer undertook his reform by unambiguously and succinctly identifying every star visible to the naked eye. He named each star, per constellation, with Greek or Latin letters (alphabet characters) in order of magnitude and placed on his star charts. In addition, Bayer reproduced the traditional numeration of the stars in the constellations, as well as the many and very different names used by Ptolemy and his successors. In this way, he sought to facilitate the identification of any star in his '*Uranometria*' with the same star as it had been recorded by his various predecessors. Bayer's nomenclature known as 'Bayer's names' has been still used widely for most stars visible to the naked eye. In this work, Bayer added 12 southern constellations to Ptolemy's original 48. It depicts the positions and magnitudes of about 1200 stars. We used his reprinted edition.

2.3.6 *Historia Coelestis Britannica*

John Flamsteed (*b.* Denby, England, 19 August 1646; *d.* Greenwich, England, 31 December 1719) engaged in positional astronomy at Royal Greenwich Observatory and made 20,000 observations of nearly 3,000 stars. His observational data were partly compiled in '*Historia Coelestis*' in 1712 and completely in '*Historia Coelestis Britannica*' (1725), published after his death. In '*Historia Coelestis Britannica*', his records are spread out over three volumes of which the first two include data on planetary movement (I: 1675–1689, II: 1689–1720). His star catalogue, including stellar equatorial coordinates, ecliptic coordinates and magnitudes is contained in Tome (Volume) III. The observation epochs are described in the catalogue; the mean epoch is 1689. We investigated an original '*Historia Coelestis Britannica*' kept in Paris Observatory.

Another work of Flamsteed '*Atlas Coelestis*' was published in 1729. In 1776, 2nd edition of this work was edited by Fortin and published in Paris as '*Atlas Céleste de Flamstéed*'. In 1968 it was translated into Japanese and published as 'フラムスチード天球圖譜' by Kouseisha. This Japanese edition included a star catalogue. In this catalogue, stellar magnitudes were recorded and we first intended to use these magnitudes as data at this epoch. However, the number of records was very little (386 stars) and it is difficult to refer due to errors and obscurities. The original edition of '*Atlas Coelestis*' is comprised of star charts only and did not include observational data. Using the 3rd edition '*Atlas Céleste de Flamstéed*' kept in Paris Observatory, we could correct errors and clear obscure parts in the Japanese edition. (We could not know whether these errors were due to misprints of original work or due to transcriptional mistakes through the translation.) This edition includes data of 858 stars and we found that the 3rd edition had been furthermore edited by other persons, Lalande and Méchain in 1795. Because

PARS PRIMA.

Complectens, nomina omnium constellationum, quæ ab Ecliptica ad eius polum Boreum vergunt, vnà cum ordine, numero antiquo, nouiterq; adaucto, longitudinibus, latitudinibus, atque magnitudinibus Stellarum.

TABVLA PRIMA.

VRSA MINOR.

SEptentrio, Arctos minor, Cynosura, Phœnice, Ἄμαξα, Plaustrum seu Plostrum minus, Eruccabah, Ezra.

DIARTHROSIS.

1 α CAuda extima, seu stella polaris, nauigatoria, Stella maris, la tramontana, Alruccabah, seu Ruccabah Ismaëlitis. — 2 {Secundæ.
6 β Earum quæ in seq: latere australior. Kochab.
7 γ Eiusdem lateris borealior. — 1 {Tertiæ. {differentiæ.
2 δ Sequens ab Alruccabah, χορευτὴς πρῶτος.
3 ε In eductione caudæ, χορευτὴς δεύτερος. — 3 {Quartæ.
4 ζ In latere quadranguli præcedente, australis.
5 η Eiusdem lateris borealior. — 2 {Quintæ.
8 θ In latere quadranguli pcedente, australior. — 1 {Sextæ.

Omnes de natura ♂ & ♀.

Reliquæ passim adhibitæ, & omnibus propè sideribus quasi adspersæ, in formas ab antiquis frequentatas, aptè cogi non potuerunt: idcirco ἀμόρφωτοι, id est informes, ab aliis σποράδες, seu sparsiles appellatæ, diarthrosin nullam sortiuntur.

A Polus Zodaici Boreus.
B Polus mundi noster seu Arcticus.
C Periphæria poli B. circa polum A.
D Circulus Arcticus.
E Dodecatemorea signi cuiuslibet Charactere proprio subsignati.
F Colurus æquinoctiorum.
G Colurus Solstitiorum.
H Periphæria stellę polaris circa polum Mundi B.

Ad læuam extima numerorum series, antiquum, modernumq; stellarum ordinem designat. Succedens alphabetaria, hanc nostram præfigurat, collectaq; cuiuslibet Schediographiæ, æqualis magnitudinis astra repræsentat: sparsim quoq; per has tabulas cifræ, seu rotulæ, stellarum radiis annexæ, occurrent, quas dictarum centra interpretaberis.

A

Photo. 3 *Uranometria*

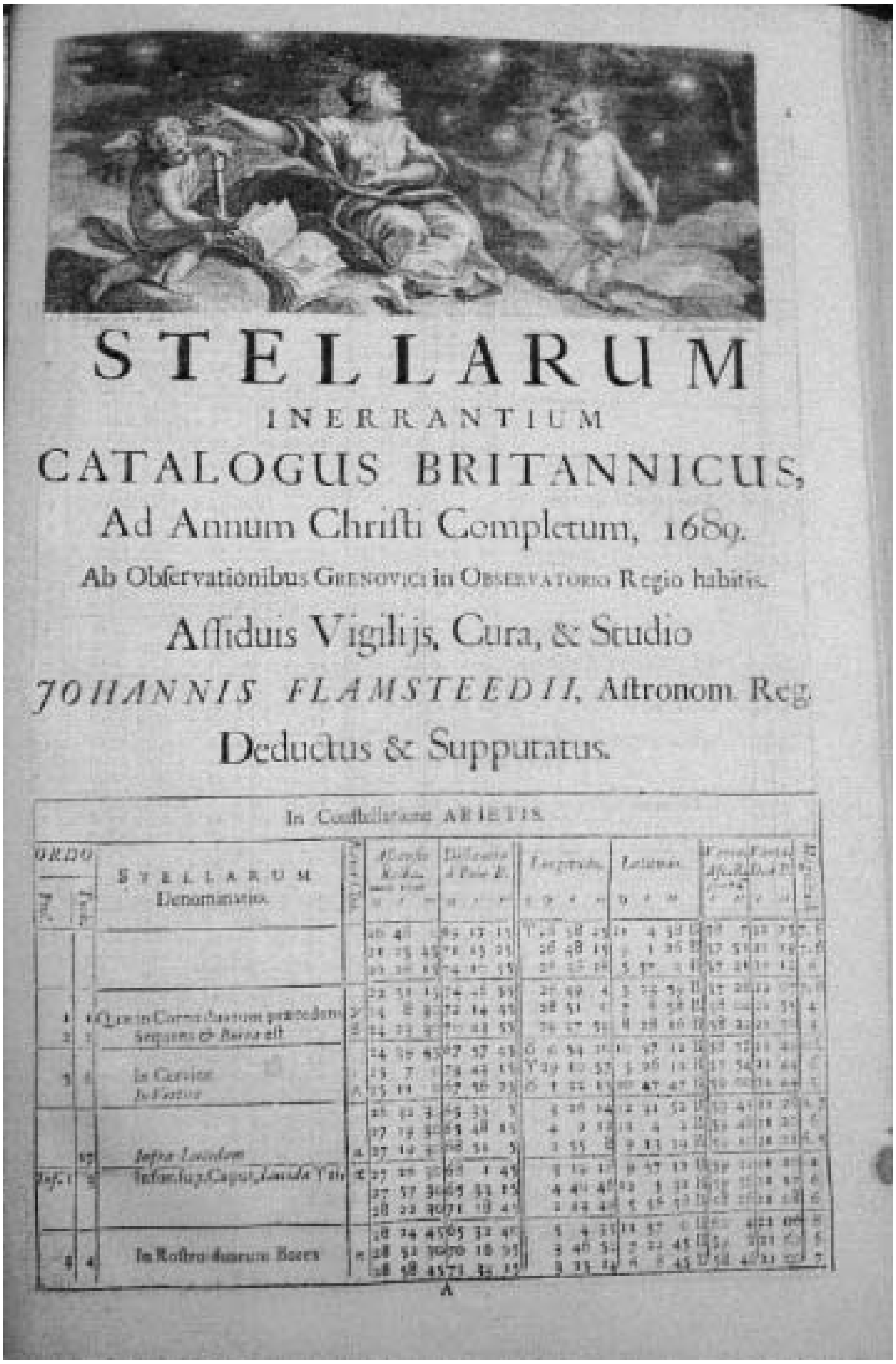
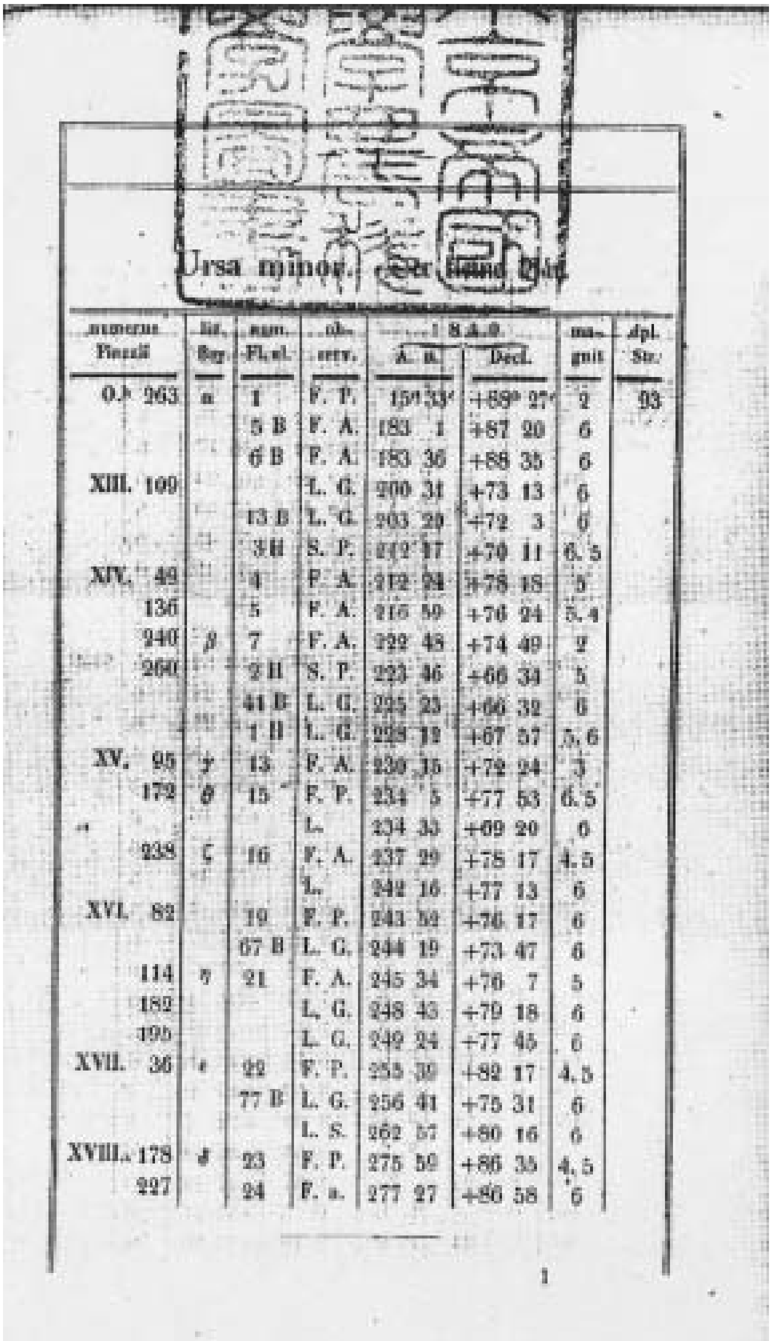


Photo. 4 *Historia Coelestis Britannica*



Ursa minor. [illegible]

numerus Piazzii	lit. Bay.	num. Fl. et	observ.	1840 A. R.	1840 Decl.	magnit	dpl. Str.
0.h 263	α	1	F. P.	15h 33′	+88° 27′	2	93
		5 B	F. A.	183 1	+87 20	6	
		6 B	F. A.	183 36	+88 35	6	
XIII. 109			L. G.	200 31	+73 13	6	
		13 B	L. G.	203 29	+72 3	6	
		3 H	S. P.	212 17	+70 11	6.5	
XIV. 49		4	F. A.	212 24	+78 18	5	
136		5	F. A.	216 59	+76 24	5.4	
240	β	7	F. A.	222 48	+74 49	2	
260		2 H	S. P.	223 46	+66 34	5	
		41 B	L. G.	225 23	+66 32	6	
		1 H	L. G.	228 12	+67 57	5.6	
XV. 95	γ	13	F. A.	230 35	+72 24	3	
172	θ	15	F. P.	234 5	+77 53	6.5	
			L.	234 35	+69 20	6	
238	ζ	16	F. A.	237 29	+78 17	4.5	
			L.	242 16	+77 13	6	
XVI. 82		19	F. P.	243 52	+76 17	6	
		67 B	L. G.	244 19	+73 47	6	
114	η	21	F. A.	245 34	+76 7	5	
182			L. G.	248 43	+79 18	6	
195			L. G.	249 24	+77 45	6	
XVII. 36	ε	22	F. P.	255 30	+82 17	4.5	
		77 B	L. G.	256 41	+75 31	6	
			L. S.	262 57	+80 16	6	
XVIII. 178	δ	23	F. P.	275 59	+86 35	4.5	
227		24	F. a.	277 27	+86 58	6	

1

Photo. 5 *Uranometria Nova*

these magnitude data had been not based on the observation of Flamsteed, we rejected it to use for this study (Fujiwara 2003).

2.3.7 *Uranometria Nova*

Friedrich Wilhelm August Argelander (*b.* Memel, Prussia, 22 March 1799; *d.* Bonn, Germany, 17 February 1875) observed a few thousand stars with the naked eye. Without measuring instruments, he created '*Uranometria Nova*' (Argelander 1843). The main feature of this work was not the determination of exact positions, but the recording of all stars visible to the naked eye and a settlement of the nomenclature that had been used arbitrarily up to this time, as well as a demarcation of the constellations of the stars. At the same time, this atlas and the accompanying catalogue fulfilled the task of a reliable representation of the magnitudes of the stars. The exact observation of stellar magnitudes was not yet possible in Argelander's time because there was no suitable photometer. Based on the ability of man's eyesight to perceive very slight differences in brightness, his estimates were useful to investigate the changing brightness of variable stars, of which only eighteen were known at that time. By qualitatively determining the changing brightness of these stars, Argelander opened a completely new field of research which soon earned an important place in the working program of many astronomers; and at his suggestion, it became of interest to many amateurs as well. At the time of his death, the number of variable stars with known period of changing light had increased to almost 200. His '*Uranometria Nova*' records 3256 stars with equatorial coordinates and magnitudes of fixed stars. We referred to a original catalogue of '*Uranometria Nova*'.

3. Data selection and analysis

In the days when these catalogues were recorded, there was no concept of zero or minus magnitude. Therefore, the stars brighter than 1 mag were omitted (see Table 6).

In addition we omitted the stars that we could not identify. For example, since Bayer recorded the six stars π^1, π^2 $\cdots$ π^6 Ori all together and described them as π Ori, we could not assign them individual magnitudes. As for the constellation 'Argo', it was divided into 4 constellations (Puppis, Pyxis, Vela, Carina) in the 18th century by Lacaille. We could not identify the stars belonging to 'Argo' in the old star catalogues. We omitted visual double stars and binaries (except for spectroscopic binaries) whose apparent distance exceeds $1'$ (limit of resolving power of the naked eye) and recorded as one single object. For example, the apparent distance between α^1 Cap and α^2 Cap is $7'$ and magnitude data recorded as 'α Cap' were rejected. For close stars (separated less than $1'$), we used the compiled magnitude from the old catalogue.

For the present-day magnitudes of close multiple stars, we used the combined magnitudes of component stars taken from the '*Sky Catalogue 2000.0*'.

Known variables with amplitude larger than 0.5 magnitude shown in Table 9 were omitted. Through the catalogues we investigated, ζ Phe was not recorded due to the low latitude.

The catalogues we used were recorded or compiled by different people at different places in

Table 9 Widely known variable stars with amplitude larger than 0.5 magnitude.

star	magnitude	period (days)	type
ζ Phe	3.91–4.42	1.6698	EA/DM
β Per (Algol)	2.12–3.39	2.8673	EA/SD
λ Tau	3.37–3.91	3.9529	EA/DM
δ Cep	3.48–4.37	5.3663	DCEP
β Lyr	3.25–4.36	12.914	EB
o Cet (Mira)	2.0 –10.1	331.96	M
χ Cyg	3.3 –14.2	408.05	M
μ Cep	3.43–5.1	730.	SR
ε Aur	2.92–3.83	9892.	EA/GS

different times. Therefore, it might be possible that the listed magnitudes show discrepancies only because of different observational conditions. To find these discrepancies and to correct them, we compared the mean magnitude averaged over all stars listed in each study to the mean magnitude of corresponding stars listed in the '*Sky Catalogue 2000.0*'. The mean magnitudes and discrepancies thus obtained are presented in Table 10. The catalogue ID (listed in Sect. 1) is found in Column 1, the observational usually not published epoch of each catalogue is given in Column 2, the total number of stars in each catalogue N_{total} is shown in Column 3, the number of selected stars N is listed in Column 4, the ratio of selected star N/N_{total} is given in Column 5, mean magnitude of the catalogue $\bar{m}$ is listed in Column 6, present-day mean magnitude $\bar{m}_{2000}$ is given in Column 7, and $\bar{m}$ - $\bar{m}_{2000}$ is shown in Column 8. As for observational epochs, most datasets were obtained over extended periods. However, these are much shorter than the epoch differences between the catalogues. We therefore neglected errors of several years and adopted probable epochs. Consequently, we sampled, in total, 2123 naked-eye stars.

According to the catalogues, the number of selected stars differed greatly. For example, from the oldest catalogue, '*Almagest*', out of 1022 stars, we use 910 (89%), however only 1946 stars out of 3256 (60%) are taken from the most recent and probably most reliable list (Argelander). Relative to the catalogue of Flamsteed, we accepted only 30%. In the case of these two catalogues there were special reasons for the high rejection percentage. In Flamsteed's

Table 10 Mean magnitudes and discrepancies.

ID	*epoch*	N_{total}	N	N/N_{total}(%)	$\bar{m}$	$\bar{m}_{2000}$	$\bar{m} - \bar{m}_{2000}$
1	137	1022	910	89	3.98	4.06	–0.08
2	964	1025	911	89	4.16	4.07	0.09
3	1437	1018	889	87	4.16	4.06	0.10
4	1572	777	658	85	4.27	4.08	0.19
5	1603	~ 1200	949	~ 79	4.42	4.26	0.16
6	1689	~ 3000	1003	~ 33	4.61	4.36	0.25
7	1843	3256	1946	60	5.03	4.81	0.22

catalogue, there were many stars without identification marks (Bayer names or Flamsteed's numbers) which were not selected. Flamsteed's numbers were not found in '*Historia Coelestis Britannica*' which we could investigate at Paris Observatory. As for the catalogue of Argelander, the stars identified by neither Bayer names nor Flamsteed's numbers were not sampled. We could not associate the other identification marks with currently known ones. Therefore, we used the stars marked with common identifications.

4. Results and discussion

4.1 Independence of catalogues

In order to investigate whether these catalogues were based on individual observations or copied from predecessors, we compared these seven catalogues to each other. If one material was copied from predecessors, their magnitude data would be identical and the distribution of stellar magnitude differences would have a very small standard deviation. If the standard deviation is large, we could assume that the magnitude data was observed independently. The distribution of the differences of stellar magnitudes between each pair of studies is shown in Fig. 1.

The standard deviations σ of these distributions and the numbers of sampled stars N are given in Table 11. In order to clarify the value of the standard deviations, we set the average of the magnitude difference for a pair of catalogues at zero by adding a small (up to 0.1 mag) constant for each pair.

With the exception of the correlation between '*Ṣuwar al-Kawākib*' and Ulugh Beg's catalogue, the standard deviations σ range from 0.40 to 0.78 mag for all catalogue comparisons. These values are much larger than expected for non-independent records. Therefore, the stellar magnitudes listed in these catalogues are considered to have been observed independently.

The correlation between '*Ṣuwar al-Kawākib*' (964) and '*Ulugh Beg's Catalogue of stars*' (1437) is very close with little to no deviation. In Fig.1, one can see the large peak in the distribution difference graph comparing these two sets.

Despite a span of over 450 years, the dispersion σ is much smaller than in the other correlations. However, if most of Ulugh Beg's catalogue were copied from '*Ṣuwar al-Kawākib*', the dispersion should be close to 0. The standard deviation of 0.29 mag indicates that Ulugh Beg's catalogue is not a complete copy, but gives strong reasons to suspect that the two catalogues are not fully independent either.

4.2 Consistency of magnitudes

In addition to the comparison above, we compared the stellar magnitudes in these old surveys with those in the '*Sky Catalogue 2000.0*'. The standard deviations σ of these distributions are shown in Table 11, and the number of sampled stars N are given in Table 10.

The standard deviations σ range between 0.41 and 0.70 throughout all of the catalogues. And magnitude differences measured for any combination of old catalogue and the '*Sky Catalogue 2000.0*' show a Gaussian distribution (see Fig. 2). All of these facts demonstrate that

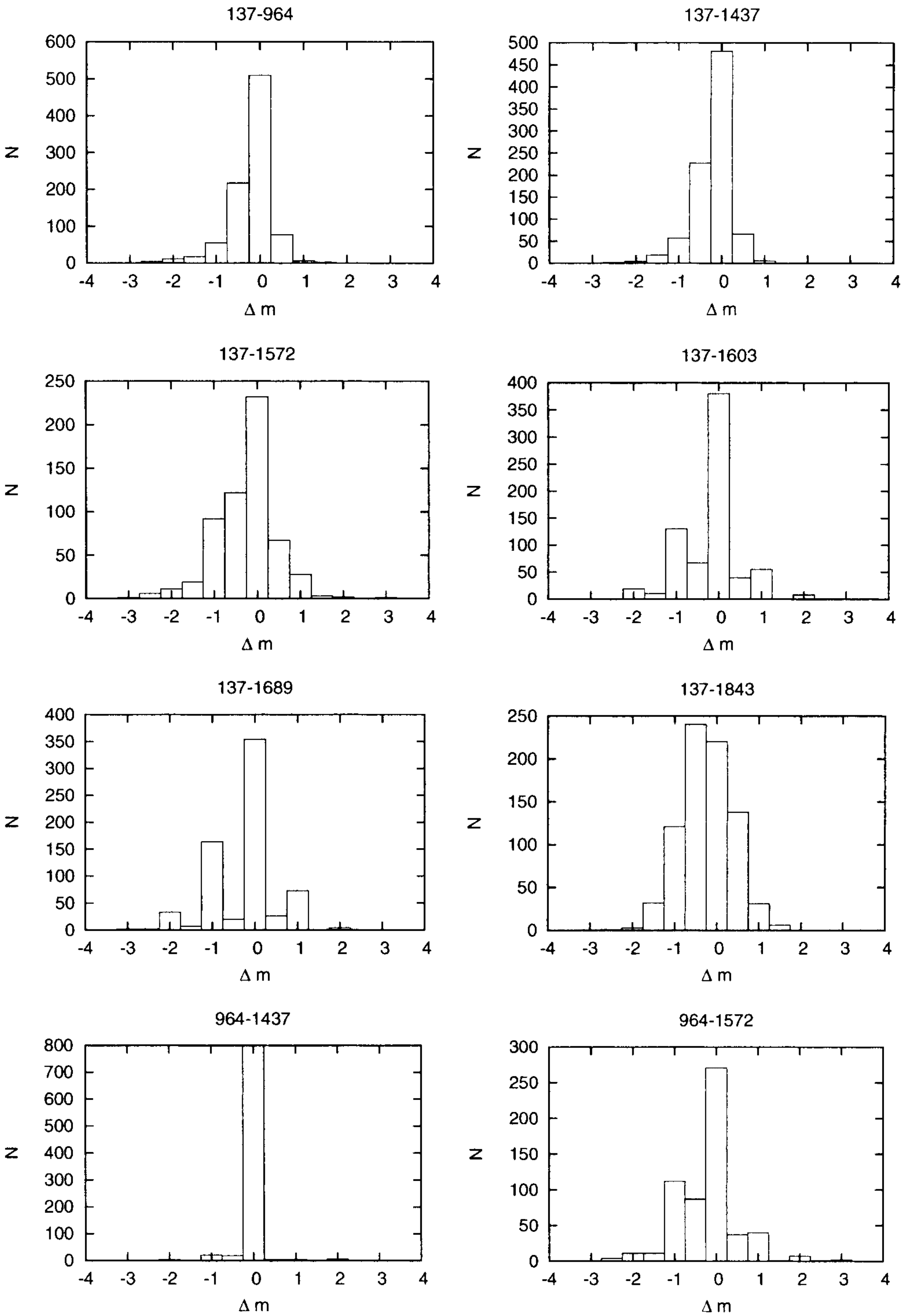


Figure 1 Differences of stellar magnitude between two old catalogues.

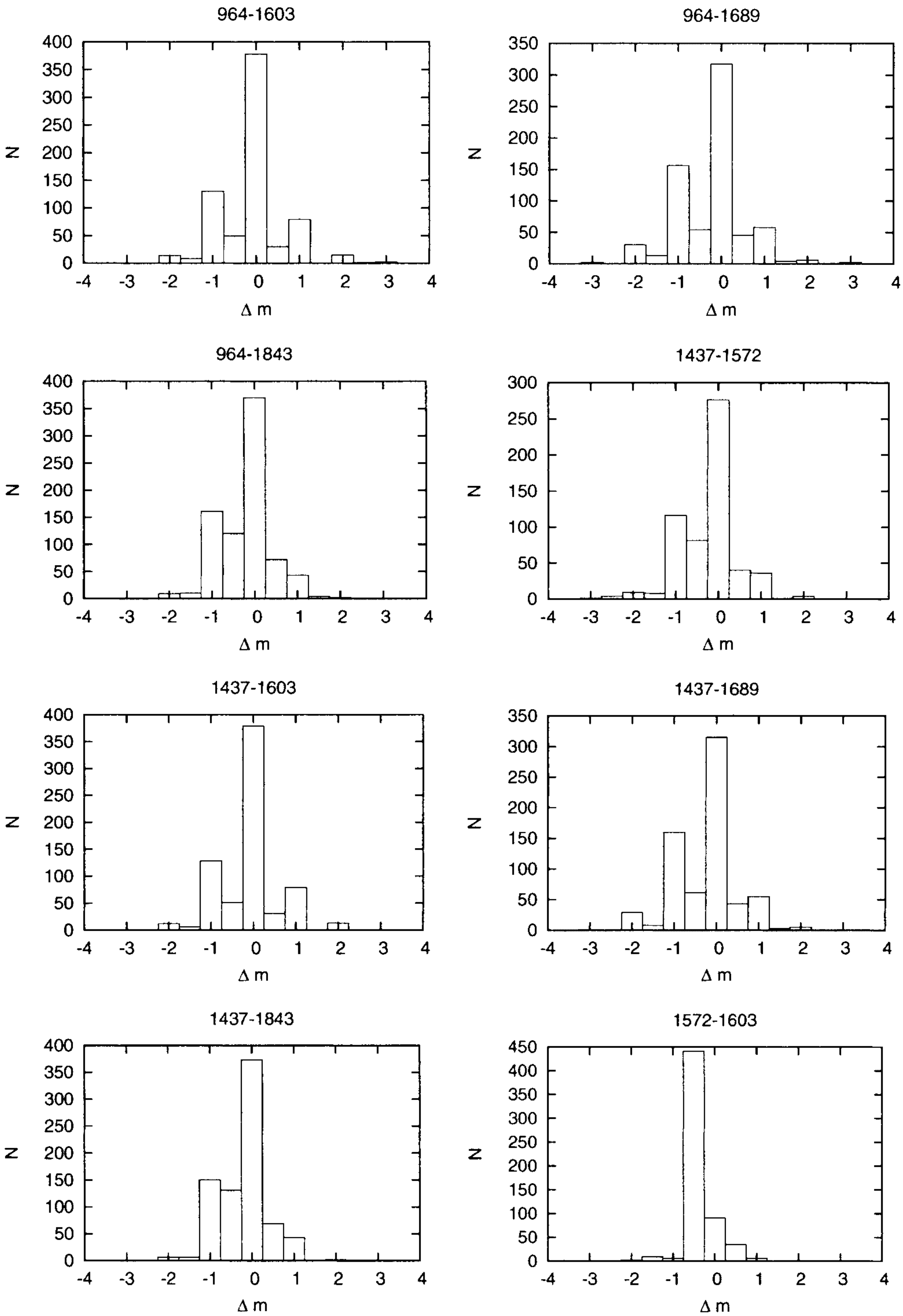


Figure 1 (Continued)

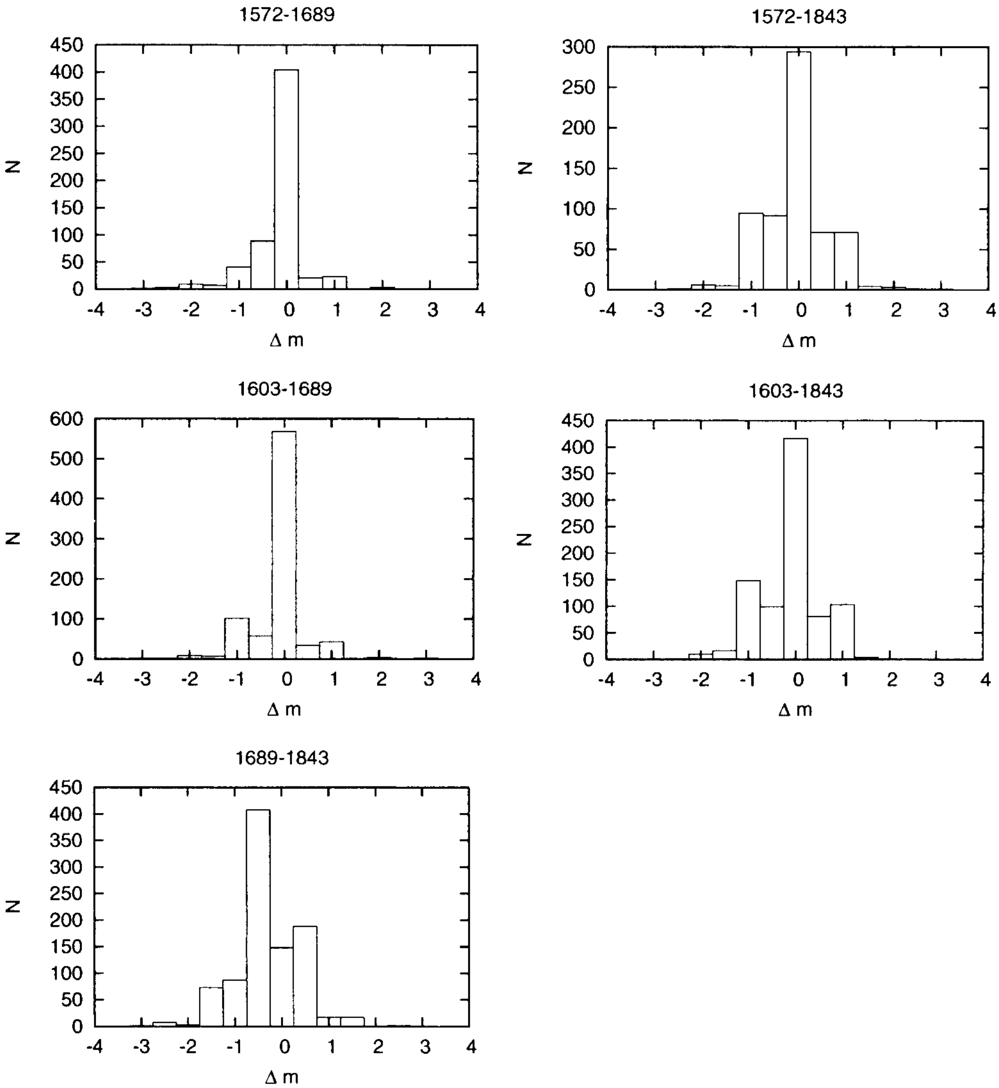


Figure 1 (Continued)

their magnitude variations are considered to be real when the variation is sufficiently larger than the dispersion. Therefore, we can use these star catalogues as scientific data within an average intrinsic uncertainty of about 0.5 mag.

We show discrepancies between the mean magnitude of the catalogue $\bar{m}$ and the present-day mean magnitude $\bar{m}_{2000}$ in each catalogues as $\bar{m}$ - $\bar{m}_{2000}$ in Table 10. These discrepancies are much less than 0.5, therefore, they should not militate for the discussion of dispersions. At later epochs, the value shifts toward more positive residuals. At the later epochs, the more stars were recorded. We guess these discrepancies were ascribable to the number of dimmest stars

Table 11 Standard deviations σ between two old catalogues and numbers of sampled stars N.

epoch		137	964	1437	1572	1603	1689	1843
					σ			
137		—	0.47	0.41	0.69	0.67	0.77	0.62
964		901	—	0.29	0.72	0.72	0.78	0.60
1437		860	861	—	0.66	0.68	0.72	0.55
1572	*N*	584	585	575	—	0.40	0.54	0.65
1603		709	706	699	593	—	0.59	0.65
1689		688	688	680	602	832	—	0.67
1843		792	793	780	644	878	952	—

Table 12 Standard deviations σ between old catalogues and '*Sky Catalogue 2000.0*'.

epoch	2000
	σ
137	0.64
964	0.61
1437	0.56
1572	0.67
1603	0.70
1689	0.70
1843	0.41

which were estimated imprecisely.

4.3 Magnitude systems in old star catalogues

4.3.1 Verification of historical magnitudes

Before the investigation of magnitude systems, we check whether the distribution of dispersions depends on stellar magnitude or not. Stellar magnitudes in old star catalogues distribute similarly per each magnitude class.

As shown in Table 13, for 2–5 mag, recorded magnitudes in each star catalogue are equal to corresponding current magnitudes. However, with respect to 1st magnitude in old star catalogues, each average of stars recorded as '1' is deviated toward the dimmer magnitude. As shown in Sect. 3, we omitted stars recorded as 1 mag considering as unsuitable. As well as 1st magnitude in old star catalogues, each average of stars recorded as '6' is deviated toward the brighter magnitude. Considering the present ranges of each magnitude, 3rd mag includes stars of 2.5–3.4 mag and 6th mag includes stars of 5.5–6.4 mag. However, ancient observers defined that the limit of the observable magnitude with the naked eye was 6, so their records did not contain stars dimmer than 6.0 mag. In old star catalogues, 5.5–6.0 magnitude stars were estimated as 6 mag; they recorded only the brightest stars in the range of the 6th mag. In '*Historia*

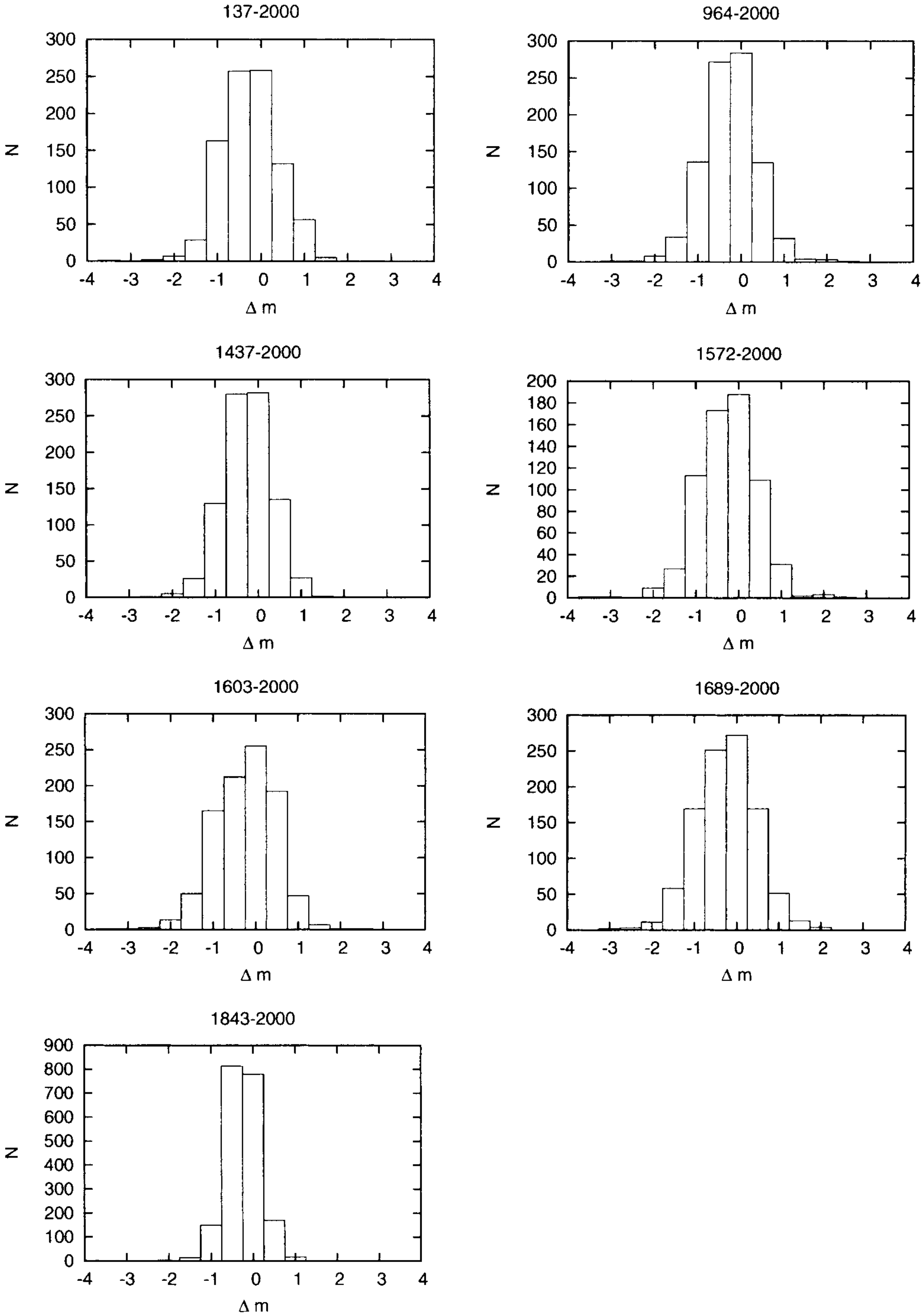


Figure 2 Differences of stellar magnitude between old catalogues and '*Sky Catalogue 2000.0*'.

Table 13 Verification of magnitudes in old star catalogues.

recorded magnitude	137	964	1437	1572	1603	1689	1843
1st	1.78	1.87	1.55	1.23	1.81	1.36	—
2nd	2.12	1.90	1.93	2.17	2.18	2.23	2.06
3rd	3.15	2.85	2.78	3.22	3.23	3.18	3.03
4th	4.23	4.17	4.15	4.05	4.13	4.11	4.01
5th	4.82	4.65	4.67	4.59	4.67	4.70	4.86
6th	5.26	5.13	5.17	5.11	5.21	5.15	5.58

Coelestis Britannica' (1689), Flamsteed observed and recorded stars of 7th magnitude which was not precisely defined at that time. These stars should be considered to be estimated imprecisely. In this study, the data of 7th mag are within the purview of references and we could not treat them as authoritative data.

In Fig. 3, we compare distributions of dispersion ($m_{137} - m_{2000}$) in '*Almagest*' per recorded magnitudes (3rd and 6th). The distribution of 3rd mag is symmetric around 3.0 mag. On the other hand, the distribution curve of 6th mag is not symmetric and found to be cut off. Near the observable limit (6.0), there should be recorded stars and non-recorded stars on a fifty-

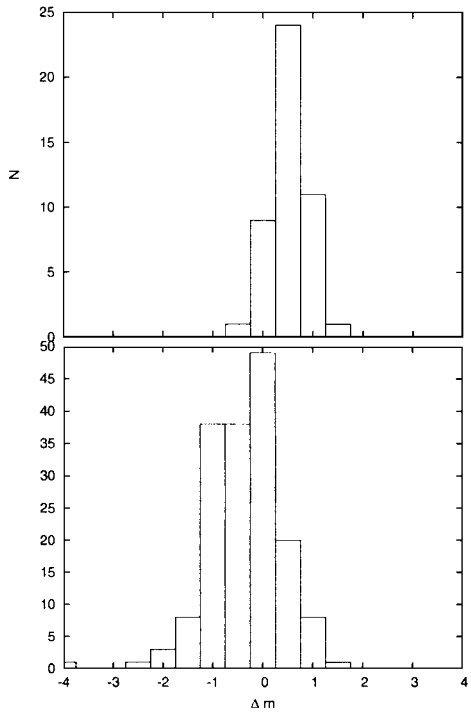


Figure 3 Differences of distributions of dispersions between 6th (above) and 3rd (below) magnitudes.

Table 14 Standard deviation σ of each recorded magnitude in '*Almagest*'.

magnitude	σ
1st	0.91
2nd	0.66
3rd	0.73
4th	0.56
5th	0.51
6th	0.39

fifty basis (Malmquist bias). Because we could observe and also could not observe stars of observable limit 6th magnitude. Therefore, the number of stars of 6.0 mag should exist more, and the true peak of the distribution for 6th mag should be at 6.0. As clearly shown in Fig 3, the distribution of 6th and 3rd magnitude is common for the brighter part, however, for the dimmer part, the distribution of 6th mag is inhibited. As shown in Table 14, the standard deviation σ of 6th mag in '*Almagest*' is much smaller than the others. It suggests that the distribution of 6th mag is cut off in half. This inhibition should be due to the observational limit with the naked eye, and the criterion of 6th magnitude in old star catalogues should correspond with the same class of Pogson's system. As well as 6th magnitude, the distribution of 5th magnitude should be cut off, however, most parts in this distribution are within the range of magnitudes brighter than 6th. Therefore, the part cut off is found to militate hardly for our results.

4.3.2 logarithm vs. power law

We compared each magnitude system of seven old star catalogues to Pogson's magnitude system. First, we investigated magnitude data in old catalogues on the chart based on the logarithmic magnitude scale. As shown in the previous section, some data points have to be excluded because of characteristics of records. In Fig. 4, the present magnitudes of stars recorded in each star catalogue are dotted lines and it is naturally equivalent to Pogson's scale. The solid lines indicate the best-fit linear regressions of old magnitudes. In drawing linear regressions, we omitted all data points recorded 1 or 6 mag in old star catalogues.

Secondly, we plotted the same magnitude data on a power-law scale chart (see Fig. 5). The function of Schulman & Cox is given as

$$m = 5.5556(2.512^{(-0.5)(6-V)}) + 0.4444. \qquad (4.\ 1)$$

This scale is indicated with dotted lines and power-law regressions are shown with solid lines.

In this study, we compared the magnitude system based on the logarithmic scale with that on the power-law scale. As shown in Fig. 4, on the logarithmic scale, magnitude data recorded in old catalogues correspond exactly with Pogson's logarithmic scale.

It can be seen from Fig. 5 that the function suggested by Schulman & Cox does not at all fit to the magnitude data in old star catalogues. Relative to power-law regressions shown with solid lines, for dimmer magnitudes (3–6) regressed functions fit to the magnitude data, on the

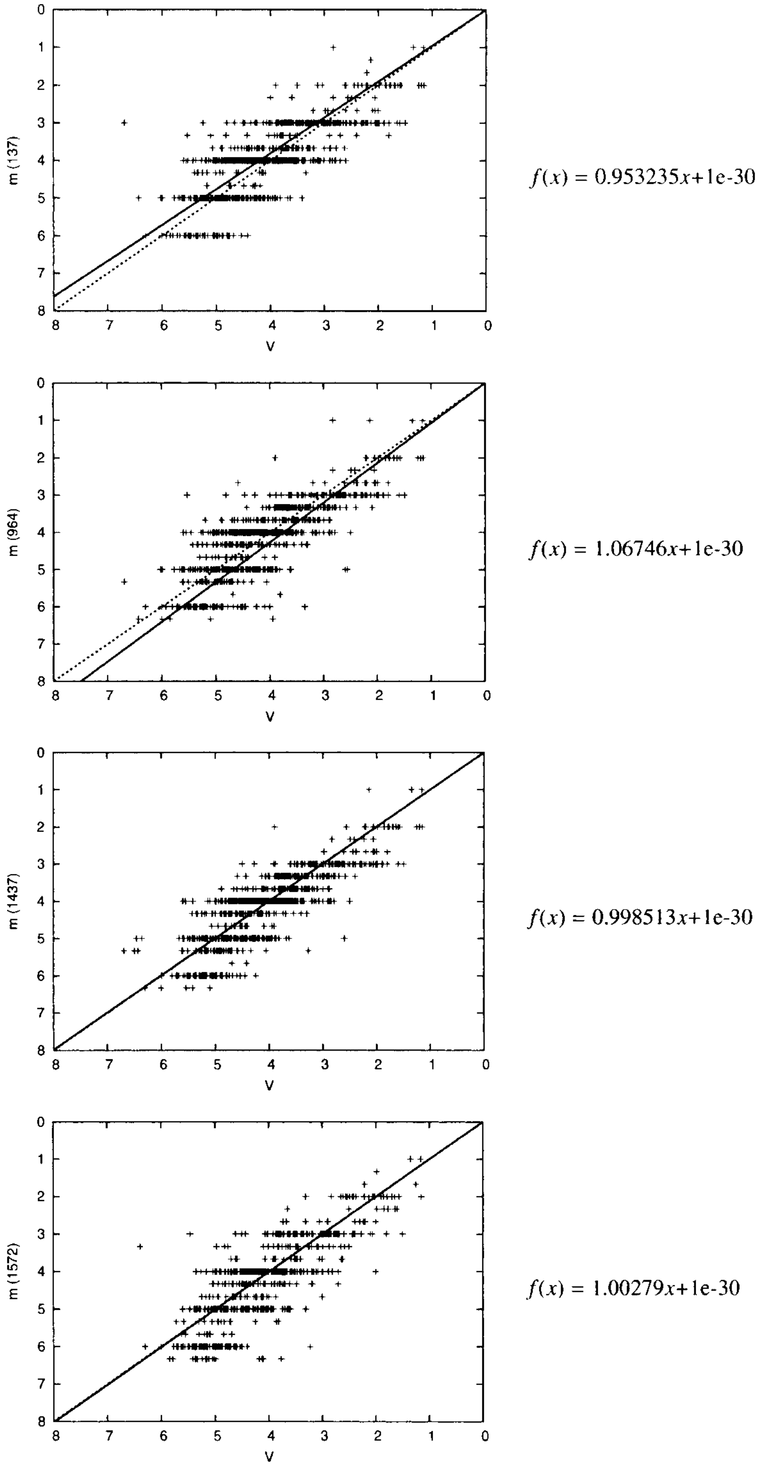


Figure 4 Magnitude systems on the logarithmic scale. Dotted lines indicate Pogson's scale and solid lines indicate the best-fit linear regressions expressed by the functions.

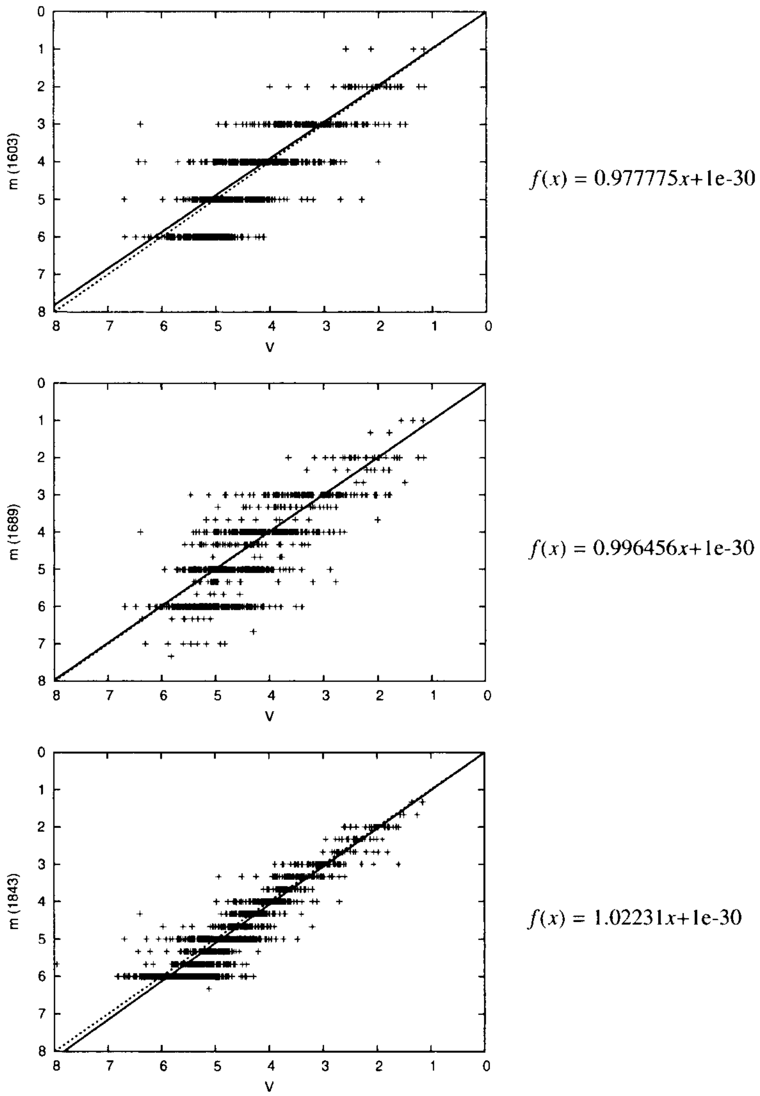
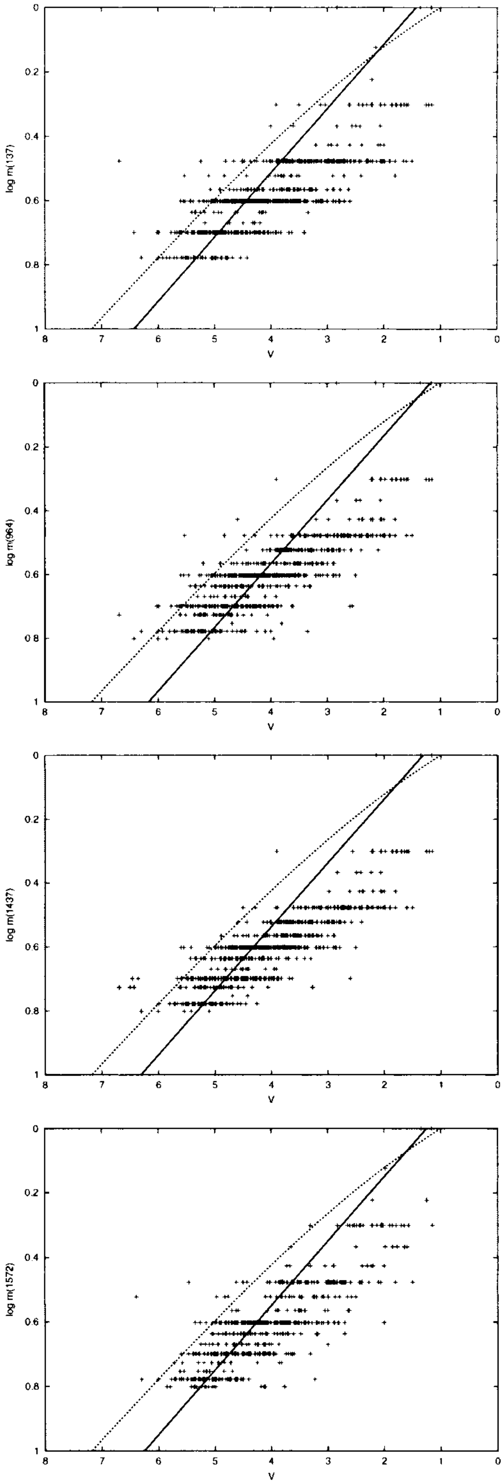


Figure 4 (Continued)

contrary, those for brighter magnitudes (1–3) deviate notably. We could not say that magnitudes fitted to a power-law system unless the data did not have a bias toward proportions at all points on a power-law scale chart.

In order to investigate which scale is better for the magnitude data in old star catalogues, we estimate by chi-square tests. In Table 15, we can see reduced chi-squares. Observational epoch is found in Column 1, the reduced chi-square $\chi_\nu{}^2$ on the logarithmic scale are shown in Column 2, and on the power-law scale the reduced chi-square $\chi_\nu{}^2$ are shown in Column 3. If a regressed function fits to the data, the reduced chi-square $\chi_\nu{}^2$ should be small.



$f(x) = 8.20078+1\text{e-}30$

$f(x) = 9.25221+1\text{e-}30$

$f(x) = 8.66272+1\text{e-}30$

$f(x) = 8.91483+1\text{e-}30$

Figure 5 Magnitude systems on the power law scale. Dotted lines indicate the function of Schulman & Cox and solid lines indicate the best-fit power-law regressions.

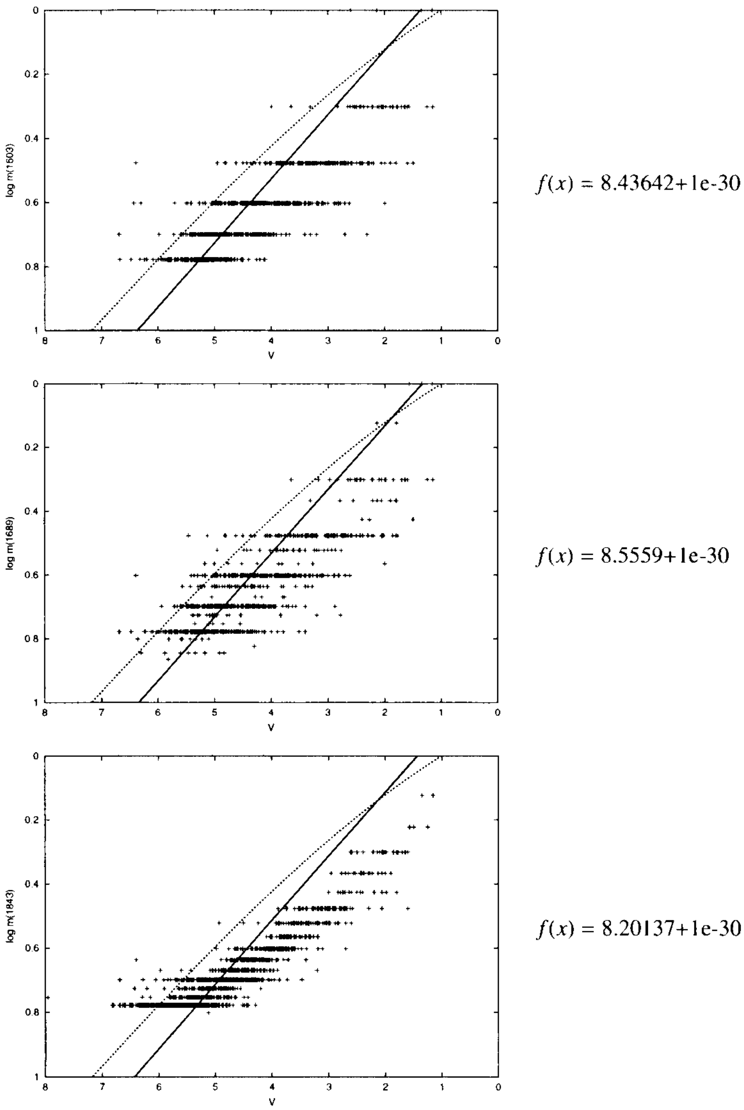


Figure 5 (Continued)

As shown in Table 15, all reduced chi-squares $\chi_\nu{}^2$ on the logarithmic scale are much small, i.e. estimated linear regressions are almost proper. Contrarily, on the power-law scale, each reduced chi-square is too large. It means that regressions on power-law scale could be alterable to another function, and estimated regressions do not fit at all. It suggests that historical magnitudes also disagree with a power-law system. Magnitude systems in all old star catalogues do

Table 15 Reduced chi-square in old star catalogues on logarithmic and power-law scale.

epoch	χ^2_ν (logarithm)	χ^2_ν (power-law)
137	0.36265	1.13955
964	0.27199	0.48512
1437	0.28527	1.08446
1572	0.37404	1.01785
1603	0.42962	1.28275
1689	0.38853	1.09758
1843	0.14192	0.92862

not fit to the power-law scale but instead, to the logarithmic scale.

4.3.3 Examination of the light ratio

In the previous section, magnitude systems are found to fit to the logarithmic scale. Subsequently, we examine light ratios R of magnitude systems in old star catalogues. In Table 16, we calculate R in each star catalogue through linear regressions (see Fig. 4). Each R in old star catalogues approximates to Pogson's $R = 2.512$.

Relative to the magnitude system and the light ratio R in *'Almagest'*, Hearnshaw explained to be logarithmic scale of $R = 3.26$ (1996), and revised $R = 3.42$ (1999). These values incline away from Pogson's system. Using all magnitudes recorded in *'Almagest'*, we confirmed that the light ratio of its system had corresponded to Hearnshaw's value. However, we suggest that this difference between Pogson's and Hearnshaw's value should be ascribable to the marginal magnitudes; the brightest magnitude (1st) and the dimmest magnitudes (6th and dimmer). In order to know real systems of magnitude, we cut inaccurate 1st, 6th and dimmer mag to draw linear regression. As shown in Fig 4 and in Table 16, magnitude systems in old star catalogues, including *'Almagest'*, fit to Pogson's scale ($R = 2.512$).

Table 16 Light ratio R in old star catalogues.

epoch	R
137	2.615
964	2.360
1437	2.505
1572	2.495
1603	2.554
1689	2.509
1843	2.451

4.4 Candidates of stars with long-term variability

4.4.1 Stars with large magnitude variation

Through previous investigations, we found that seven old star catalogues were obtained from independent observations, that magnitude variations could be considered to be real and that their magnitude systems correspond to current magnitude system of Pogson. In this subsection, we present candidates of stars with long-term variability found in the course of our analysis.

First, we corrected $\bar{m} - \bar{m}_{2000}$ found in Table 10, regarding as a personal error of observation and estimation. Second, we compared corrected magnitude data for 2123 stars through all observational epochs.

Table 17 shows distribution statistics of catalogued stars according to magnitude variation. Most of stars recorded in old star catalogues show little or no magnitude variation. The ratio of stars with magnitude variation not more than 1.00 totals up to 73.86 %. Conversely, only a few stars show large magnitude variation.

In Table 18, we list ten stars showing the largest magnitude variations among 2123 stars.

The stars with magnitude variation larger than 3σ (99.7% confidence level) could be considered to have changed their magnitudes during these $\sim$ 2000 years. The value of σ is various according as star catalogues (see Table 12), however, considering that all values of σ are less than 1.00, the magnitude variation larger than $\sim$ 3 mag could be sufficiently considered to be real.

4.4.2 Astrophysical basic data

We present astrophysical natures already detected of each star listed in Table 18.

Table 17 Distribution statistics of catalogued stars according to magnitude variation.

magnitude variation	N	N/N_{total}(%)
$0.00 \leq \Delta m \leq 0.50$	946	44.56
$0.50 < \Delta m \leq 1.00$	622	29.30
$1.00 < \Delta m \leq 1.50$	401	18.89
$1.50 < \Delta m \leq 2.00$	84	3.96
$2.00 < \Delta m \leq 2.50$	52	2.45
$2.50 < \Delta m \leq 3.00$	10	0.47
$3.00 < \Delta m$	8	0.38
N_{total}	2123	

Table 18 10 stars with the largest magnitude variations.

star	137	964	1437	1572	1603	1689	1843	m_{2000}	Δm
α Sgr	2.41[a1]	4.24[b1]	4.23	—	1.84	5.75	—	4.00	3.91
61 Her	3.08[a2]	5.24[b2]	5.23	—	4.84	5.75	4.78	6.69	3.61
θ2 Ori	—	—	—	3.14	2.84	3.75	—	6.39	3.55
38 Aqr	6.08[a3]	5.91	—	2.81	5.84	2.75	5.11	5.46	3.33
γ CMa	4.08	5.91[b3]	3.90	3.14	2.84	2.75	4.11	4.10	3.16
δ Leo	2.41[a4]	4.91[b4]	1.90	1.81	1.84	2.08	2.11	2.56	3.10
5 Her	—	—	—	—	5.84	2.75	5.45	5.12	3.09
θ Aql	3.08	2.91	2.90	5.81	2.84	2.75	2.78	3.23	3.06
ζ Vir	3.08	3.24	3.23	2.81	2.84	5.75	3.11	3.40	2.94
ε Cnc	—	—	neb.	neb.	3.84	6.75	—	6.30	2.91

[a1] 2–4 mag.: depends on manuscripts (Kunitzsch 1986–1991)
[a2] 3, 5 mag.
[a3] 4–6 mag.
[a4] 2–, 2+ mag.
[b1] 3 mag. in al-Bīrūnī 1030
[b2] –mag.
[b3] 4 mag.
[b4] 2 mag.

α Sgr

HD 181869	
R.A.(J2000.0) (h:m:s)	19 23 53.176
Decl.(J2000.0) (d:m:s)	−40 36 57.38
Spectral type	B8V
Distance (pc)	52

Although, according to Simbad Data Base, this object is classified as a ‘pulsating variable star’, Hipprcos Satellite photometry shows no variation up to 0.1 mag. It was classified as normal ‘Star’ until several months before, therefore, it could be a citational mistake from references[1)].

The magnitude variation of α Sgr is discussed in detail in Sect. 4.4.3.

61 Her

HD 154356	
R.A.(J2000.0) (h:m:s)	17 03 30.215
Decl.(J2000.0) (d:m:s)	+ 35 24 50.58
Spectral type	M4III
Distance (pc)	213

This object is recognized as a variable star V931 Her of LB type. The amplitude is small 6.07–6.26 mag (not V band but redder than V measured by Hipparcos Satellite). The period has not been found.

Currently, the magnitude of 61 Her is 6.69, not can be observed with the naked eye. Nevertheless, it has been observed and recorded in most historical star catalogues. It could be considered that this object had been brighter in the past.

θ2 Ori

HD 37041	
R.A.(J2000.0) (h:m:s)	05 35 22.901
Decl.(J2000.0) (d:m:s)	−05 24 57.81
Spectral type	O9.5Vpe
Distance (pc)	581

This object consists of spectroscopic binary. Furthermore, there are 206 objects within 1′ around θ2 Ori. Because θ2 Ori is in the Orion nebula cluster (Ori A) known as M42. The Orion nebula cluster can be observed with the naked eye and it could be considered difficult to distinguish this object from the bright and cloudy nebula cluster.

38 Aqr

HD 210424	
R.A.(J2000.0) (h:m:s)	22 10 37.482
Decl.(J2000.0) (d:m:s)	−11 33 53.78
Spectral type	B5III
Distance (pc)	172

This object is classified as a normal Star. No peculiar property is found.

In the historical catalogues, it was recognized twice over (1572, 1689) to have brightened up to 3 mag.

γ CMa

HD 53244	
R.A.(J2000.0) (h:m:s)	07 03 45.493
Decl.(J2000.0) (d:m:s)	−15 37 59.83
Spectral type	B8II
Distance (pc)	123

This object is a star in a cluster, however, no peculiar property is found.

Considering the errors in manuscripts, the magnitude variation of γ CMa is doubtful.

δ Leo

HD 97603	
R.A.(J2000.0) (h:m:s)	11 14 06.501
Decl.(J2000.0) (d:m:s)	+ 20 31 25.38
Spectral type	A4V
Distance (pc)	18

This object is a variable star registered as NSV 05143. The amplitude is 2.54–2.57. However, NSV 05143 is classified into the type unique variable stars outside the range of the general classifications. This type of stars probably represent either short stages of transition from one variability type to another or the earliest and latest evolutionary stages of these types, or they are insufficiently studied members of future new types of variables.

Nevertheless, considering the errors in manuscripts, the magnitude of δ Leo have been constant around 2 mag.

5 Her

HD 143666	
R.A.(J2000.0) (h:m:s)	16 01 14.318
Decl.(J2000.0) (d:m:s)	+ 17 49 06.23
Spectral type	G8IIIb
Distance (pc)	95

This object is classified as a normal Star. No peculiar property is found.

θ Aql

HD 191692	
R.A.(J2000.0) (h:m:s)	20 11 18.285
Decl.(J2000.0) (d:m:s)	−00 49 17.26
Spectral type	B9.5III
Distance (pc)	88

This object is classified as a normal Star. No peculiar property is found.

ζ Vir

HD 118098	
R.A.(J2000.0) (h:m:s)	13 34 41.592
Decl.(J2000.0) (d:m:s)	−00 35 44.95
Spectral type	A3V
Distance (pc)	22

Table 19 α Sgr and nearby stars.

star	R. A. (h:m:s)	Decl. (d:m:s)	m_{2000}	Δm
α Sgr	19 23 53.176	− 40 36 57.38	4.00	3.91
δ CrA	19 08 20.970	− 40 29 48.13	4.59	0.64
β CrA	19 10 01.757	− 39 20 26.87	4.11	1.08
ζ CrA	19 03 06.876	− 42 05 42.38	2.60	2.30
α CrA	19 09 28.342	− 37 54 16.11	4.11	0.82
ι Sgr	19 55 15.697	− 41 52 05.84	4.13	1.15
γ CrA	19 06 25.153	− 37 03 48.54	4.26	0.82
ε CrA	18 58 43.377	− 37 06 26.49	4.87	1.21
ζ Sgr	19 02 36.669	− 29 52 48.58	3.28	0.50
τ Sgr	19 06 56.409	− 27 40 13.52	3.32	0.91
σ Sgr	18 55 15.926	− 26 17 48.20	4.13	0.69

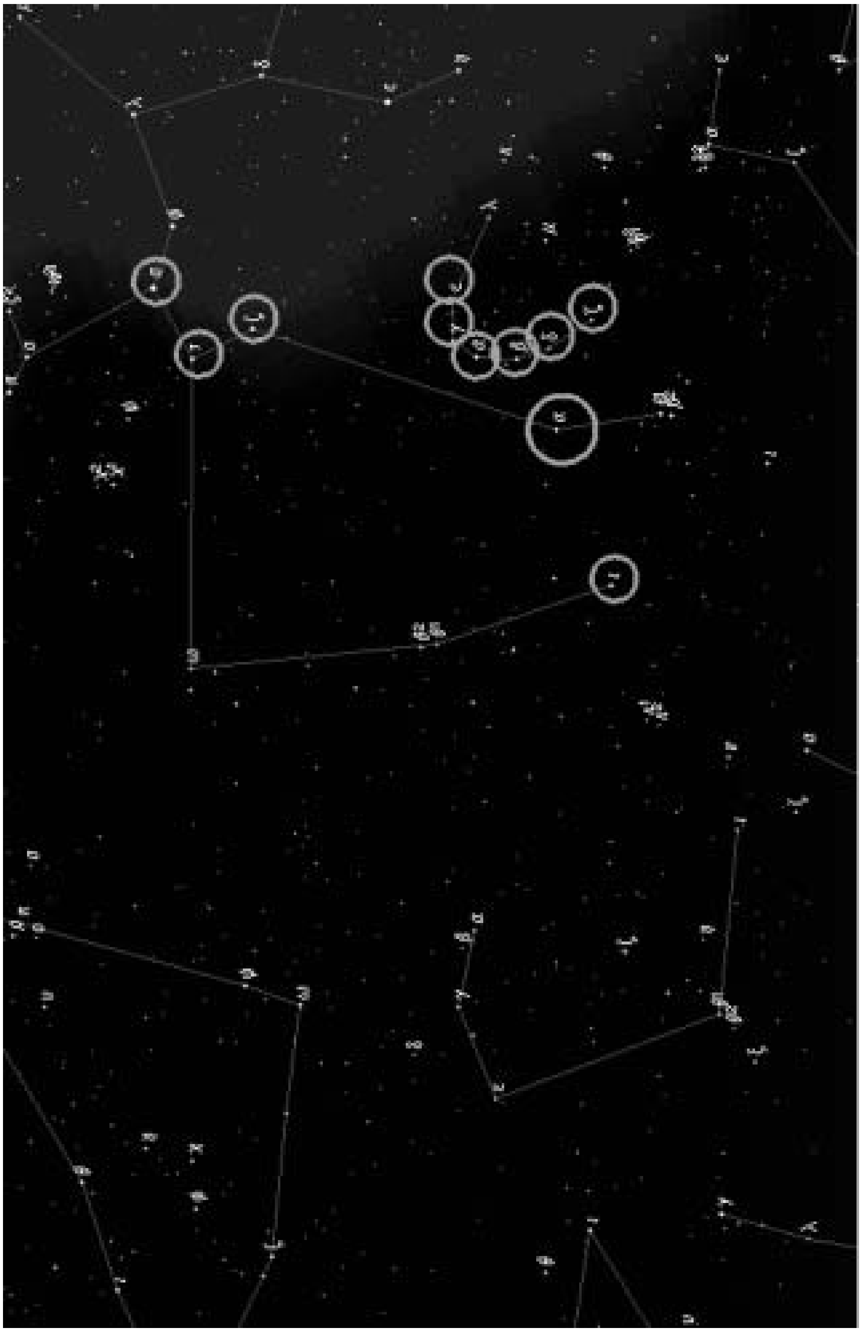


Figure 6 α Sgr and nearby stars.

This object is recognized as high proper-motion star. The quantity of this proper motion is −278.89, 48.56 (mas/yr). Relative to magnitude, no peculiar property is found.

ε Cnc

HD 73731	
R.A.(J2000.0) (h:m:s)	08 40 27.012
Decl.(J2000.0) (d:m:s)	+ 19 32 41.31
Spectral type	A5m
Distance (pc)	168

This object is in double system. Especially, ε Cnc is a member of open (galactic) cluster 'Praesepe' known as M44 (Cl* NGC 2632 RUS 209). As well as θ2 Ori, the magnitude of this star could be affected by the open cluster.

4.4.3 Magnitude variation of α Sgr

In Table 18, α Sgr shows large magnitude variation of 3.91 mag. In the case of this star, magnitude data in '*Almagest*' (137) and '*Ṣuwar al-Kawākib*' (964) are various according to manuscripts, however, they do not militate for the amplitude.

In order to check whether or not the large magnitude variation of α Sgr thus found reflect the different observational conditions, we examined the magnitude variations of other stars close to α Sgr (see Table 19 and Fig 6).

Although only the magnitude of α Sgr shows large variation $\Delta m = 3.93$ during these ~2000 years, the neighbors show very weak or no variation. In order to seek the general properties of α Sgr, we put it on the H-R diagram together with other recorded stars. On the HR diagram, as found in its spectral type, this star is on the main-sequence.

What is the cause of the magnitude variation of α Sgr? There are 2 possibilities. As regarding stellar interiors, this star is on the main-sequence and it could not be long period pulsating variables. On the other hand, as regarding stellar exteriors, this star does not consist of binary system. Only, IRAS Satellite detected infrared excess of α Sgr (Bhatte & Manoj 2000). As a Vega-like star, it is considered to be from circumstellar matter. Therefore it is possible that magnitude changed due to fluctuation of circumstellar matter distribution.

As shown in Table 18, α Sgr transiently brightened up around the epoch of Bayer (1603). However, the data of these stars we have are not enough to make sure the origin of the very long-term magnitude variations. This problem will be solved in the near future through more historical magnitude data or their detailed multiband observations.

5. Concluding remarks

Conclusion

1. The comparison of stellar magnitudes recorded in seven old catalogues indicates that the magnitudes in most of these catalogues were obtained from independent observations. Magnitude differences between old catalogues and the modern star catalogue also repre-

sent Gaussian distributions, thereby supporting the magnitude variations can be considered to be real. Essentially, the stellar magnitudes compiled in the old studies we investigated here can be used as scientific data within an average intrinsic uncertainty of about 0.5 mag.

2. In each star catalogue, recorded magnitudes from 2 to 5 are equal to corresponding current magnitudes. Since unsuitable stars of brighter than current 1.00 mag are omitted, each average of stars recorded as 1 is deviated toward the dimmer magnitude. For 6 mag, due to the observable limit with the naked eye, each average of current magnitudes is deviated toward the brighter. However, considering the Malmquist bias, the criterion of the recorded 6 mag should correspond with current 6 mag. Consequently, all magnitude systems in old star catalogues fit to Pogson's logarithmic scale not to the power-law scale suggested by Schulman & Cox. All linear regressions without 1 and 6 magnitudes fit well to the light ratio $R = 2.512$ suggested by Pogson.
3. Through 2123 data sets of stellar magnitude, most of the stars recorded in old star catalogues show little or no variation. The number of stars with magnitude variation larger than 3 mag during these ~ 2000 years amounts to 8. Especially, α Sgr shows the largest variation of 3.91 mag. Considering stellar interiors, this object is on the main-sequence and not to be a long period pulsating variable. As for stellar exteriors, this object does not consist of binary system. Only, IRAS Satellite detected infrared excess of α Sgr.

Future works

It should be considered the effect of low altitude (atmospheric reddening) by comparing the magnitude variations per latitudes or longitudes.

Additions of historical and reliable star catalogues will contribute to infill snatchy magnitude data.

Some of the stars we could not identify and omitted here might be transient objects (nova, supernova or others) caught in an outburst. In addition, the elucidation of the mechanism of long-term variability of stars, including observations is one of the most important subject for this study.

Salvare apparentias

The Universe has excited curiosity in the humankind since the ancient times. As recorded in the mythology, humanbeings have yearned the sun, the moon and stars. I think that this feeling would be similar to the nostalgia. The view of the Universe has always an implication for the civilization. Astronomy is one of the oldest fields. In order to know the system of the Universe, many people have seen the stars. They were struck with a feeling of awe. For them, astronomical phenomena that we take for granted, were mysterious. It is natural that '*o* Cet', the first star recognized as a variable, was named 'Mira (miracle)'. In fact, it made a lot of endeavors and took a long time to get a solution to the phenomenon.

The '*Almagest*' that I use for this study is famous for the theory of celestial bodies. Ptolemy tried to demonstrate with geometric model solar, lunar, and planetary movements in the geocentric system. Unfortunately, until the 17th century, the geocentric theory had been a principle and many astronomers were puzzled about discrepancies between the observation and the theory.

Salvare apparentias—to save the phenomena—, they made great efforts with mathematical methods, however, they could really save the phenomena? The mathematical theory has been parfect? I think that in order to save the phenomena, we must see (even if indirect) and know the nature. The development of observational or experimental instruments has promoted discoveries and the progress of scientific knowledge has brought with it more conspicuous enigmata. However, we must save the phenomena with the method grounded on empirical facts. All theories mathematically coherent to phenomena are not facts scientifically. In order to never lose the nature of science, we should look back the past errors. I would like to gaze at the star-spangle sky always as I used to be a child. I believe the star catalogues would be heritages that astronomers have recorded to succeed and inform us their starry sky. I compile what my heart has thought to the stars since childhood, into this thesis now.

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Appendix

A. Stellar structure and evolution and its time scale

We difine at first the following quantities.
r: the radial distance measured from the stellar center (cm)
R: the total stellar radius
$\rho(r)$: the mass density at r (g cm^{-3})
$T(r)$: the temperature at r (K)
$P(r)$: the pressure at r (dyne cm^{-2} = erg cm^{-3})
$m(r)$: the mass contained within a sphere of radius r (g)
M: the total stellar mass ($m(R)$)
$l(r)$: the luminosity of the star, the rate of energy flow through a sphere at r (erg s^{-1})
L: the total stellar luminosity ($l(R)$)
$g(r)$: the local acceleration due to gravity (cm s^{-2})
G: the gravitational constant ($= 6.6726 \times 10^{-8}$ g^{-1} cm^3 s^{-2})
$M_\odot$: the solar mass ($= 1.989 \times 10^{33}$ g)
$L_\odot$: the solor luminosity ($= 3.847 \times 10^{33}$ erg s^{-1})
$R_\odot$: the solor radius ($= 6.96 \times 10^{10}$ cm)

A.1 Basic equations

A.1.1 Equation of continuity

For gaseous, non-rotating, single stars without strong magnetic fields, the only forces acting on a mass element come from pressure and gravity. This results in a spherically symmetric configuration. All functions will then be constant on concentric spheres, and we need only one spatial variable to describe them. We use the distance r from the stellar center as the spatial coordinate, which varies from $r = 0$ at the center to the total radius $r = R$ at the surface of the star. In addition, the evolution in time t requires a dependence of all functions on t. In order to provide a convenient description of the mass distribution inside the star, in particular of its effect on the gravitational field, we define the function $m(r, t)$ as the mass contained in a sphere of radius r at the time t. Then m varies with respect to r and t according to

$$dm = 4\pi r^2 \rho dr - 4\pi r^2 \rho v dt. \tag{A. 1}$$

The first term on the right is the mass contained in the spherical shell of thickness dr, and it gives the variation of $m(r, t)$ due to a variation of r at constant t, i.e.

$$\frac{\partial m}{\partial r} = 4\pi r^2 \rho. \tag{A. 2}$$

The last term gives the spherically symmetric mass flow out of the sphere of constant radius r due to a radial velocity w in the outward direction in the time interval dt:

$$\frac{\partial m}{\partial t} = -4\pi r^2 \rho w. \tag{A. 3}$$

In the spherically symmetric case, it is useful to take a Lagrangian coordinate connecting to the mass elements instead of the spatial coordinate of r. m is the mass contained in a concentric sphere at a given moment t_0. The new independent variables are m and t, and all other variables are considered to depend on them. The radial distance r of the mass element from the center is described by the function $r = r(m, t)$. At the center $m = 0$, and the total mass $m = M$ is reached at the surface ($r = R$). While the radius R varies strongly in time, the star extends over the same interval of the independent variable $m : 0 \leq m \leq M$. Then, there will be no problem concerning a unique one-to-one transformation between the two coordinates r and m. For any function depending on two variables one of which is substituted by a new one ($r, t \to m, t$), the partial derivatives with respect to the new variables are given by

$$\frac{\partial}{\partial m} = \frac{\partial}{\partial r}\frac{\partial r}{\partial m},$$
$$\left(\frac{\partial}{\partial t}\right)_m = \frac{\partial}{\partial r} \cdot \left(\frac{\partial r}{\partial t}\right)_m + \left(\frac{\partial}{\partial t}\right)_r. \tag{A. 4}$$

In (A. 4), the left-hand side is simply $\partial m/\partial m = 1$, and the first factor on the right-hand side is equal to $4\pi r^2 \rho$. According to (A. 2), we obtain

$$\frac{\partial r}{\partial m} = \frac{1}{4\pi r^2 \rho}. \tag{A. 5}$$

A.1.2 Equation of motion

It follows from elementary potential theory that, inside a spherically symmetric body, the absolute value g of the gravitational acceleration at a given distance r from the center does not depend on the mass elements outside of r. It depends only on r and the mass within the concentric sphere of radius r, which we have called m:

$$g = \frac{Gm}{r^2}. \tag{A. 6}$$

Generally, the gravitational field inside the star can be described by a gravitational potential Φ as

$$\nabla^2\Phi = 4\pi G\rho, \tag{A. 7}$$

where ∇^2 is the Laplace operator. This is a solution of the Poisson equation. For spherical symmetry, we can write as

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial\Phi}{\partial r}\right) = 4\pi G\rho. \tag{A. 8}$$

For a given moment of time, we consider a thin spherical mass shell with an infinitesimal thickness dr at a radius r inside the star. Per unit area of the shell, the mass is ρdr, and the weight of the mass element is $-g\rho dr$. This weight is the gravitational force acting towards the center. In order to prevent the mass elements of the shell from being accelerated in this diretion, they must experience a net force due to pressure of the same absolute value, but acting outwards. This means that the shell must feel a larger pressure P_i at its interior lower boundary than the pressure P_e at its outer upper boundary. The total net force per unit area acting on the shell due to this pressure difference is

$$P_\mathrm{i} - P_\mathrm{e} = P(r) - P(r + dr) = -\frac{\partial P}{\partial r}dr. \tag{A. 9}$$

The sum of the forces arising from pressure and gravity has to be zero,

$$\frac{\partial P}{\partial r} + g\rho = 0, \tag{A. 10}$$

which gives the condition of hydrostatic equilibrium as

$$\frac{\partial P}{\partial r} = -g\rho. \tag{A. 11}$$

This shows the balance of the forces from pressure (left-hand side) and gravity (right-hand side), both per unit volume of the thin shell. Equation (A. 6) gives $g = Gm/r^2$, so that (A. 11) finally becomes

$$\frac{\partial P}{\partial r} = -\frac{Gm}{r^2}\rho. \tag{A. 12}$$

If we take m as the independent variable instead of r, we obtain the hydrostatic conduction by multiplying (A. 12) with $\partial r/\partial m = (4\pi r^2\rho)^{-1}$, according to (A. 5):

$$\frac{\partial P}{\partial m} = -\frac{Gm}{4\pi r^4}. \tag{A. 13}$$

The hydrostatic equilibrium (A. 13) is a special case of conservation of momentum. If the spherical star undergoes accelerated radial motions, we have to consider the inertia of the mass elements, which introduces an additional term. We consider again a thin shell of mass dm at the distance r from the center. Owing to the pressure gradient, this shell experiences a force per unit area f_P given by (A. 9), the right-hand side of which is easily rewritten in terms of $\partial P/\partial m$ according to (A. 5):

$$f_P = -\frac{\partial P}{\partial m} dm. \tag{A. 14}$$

The gravitational force per unit area acting on the mass shell is, with the use of (A. 6),

$$f_g = -\frac{gdm}{4\pi r^2} = -\frac{Gm}{r^2}\frac{dm}{4\pi r^2}. \tag{A. 15}$$

If the sum of the two forces is not equal to zero, the mass shell will be accelerated according to

$$\frac{dm}{4\pi r^2}\frac{\partial^2 r}{\partial t^2} = f_P + f_g. \tag{A. 16}$$

This gives with (A. 14) and (A. 15) the equation of motion as

$$\frac{1}{4\pi r^2}\frac{\partial^2 r}{\partial t^2} = -\frac{\partial P}{\partial m} - \frac{Gm}{4\pi r^4}. \tag{A. 17}$$

A.1.3 Energy conservation in stars

The luminosity l is zero at $r = 0$ and l reaches the total luminosity L of the star at the surface. If a mass shell does not expand or contract, it holds

$$dl = 4\pi r^2 \rho \varepsilon dr = \varepsilon dm, \tag{A. 18}$$

where ε is the nuclear energy released per unit mass per second, and depends on temperature and density and on the abundance of the different nuclear species that react. Therefore,

$$\frac{\partial l}{\partial m} = \varepsilon. \tag{A. 19}$$

Then, we define thermodynamic relations. The heat dq added per unit mass is defined as

$$dq = du + Pdv, \tag{A. 20}$$

where u is the internal energy per unit mass and the specific volume $v = 1/\rho$. If we define as

$$\alpha = \left(\frac{\partial \ln \rho}{\partial \ln P}\right)_T = -\frac{P}{v}\left(\frac{\partial v}{\partial P}\right)_T, \tag{A. 21}$$

$$\delta = -\left(\frac{\partial \ln \rho}{\partial \ln T}\right)_P = \frac{T}{v}\left(\frac{\partial v}{\partial T}\right)_P, \tag{A. 22}$$

the equation of state can be written as $d\rho/\rho = \alpha dP/P - \delta dT/T$. The specific heats are

$$c_P = \left(\frac{dq}{dT}\right)_P = \left(\frac{\partial u}{\partial T}\right)_P + P\left(\frac{\partial v}{\partial T}\right)_P, \tag{A. 23}$$

$$c_v = \left(\frac{dq}{dT}\right)_v = \left(\frac{\partial u}{\partial T}\right)_v, \tag{A. 24}$$

$$c_P - c_v = \left(\frac{\partial u}{\partial T}\right)_P + P\left(\frac{\partial v}{\partial T}\right)_P - \left(\frac{\partial u}{\partial T}\right)_v$$

$$= \left(\frac{\partial v}{\partial T}\right)_P \left(\frac{\partial P}{\partial T}\right)_v T \qquad \text{(A. 25)}$$

$$= T\left(\frac{\partial v}{\partial T}\right)_P \frac{P\delta}{T\alpha} = \frac{P\delta}{T\alpha} = \frac{P\delta^2}{\rho T\alpha}. \qquad \text{(A. 26)}$$

According to (A. 26), we can express

$$dq = c_P dT - \frac{\delta}{\rho} dP. \qquad \text{(A. 27)}$$

We define the adiabatic temperature gradient $\nabla_{\rm ad}$ as

$$\nabla_{\rm ad} = \left(\frac{\partial \ln T}{\partial \ln P}\right)_s , \qquad \text{(A. 28)}$$

where s indicates the constancy of entropy. For adiabatic changes, since the entropy has to remain constant, namely $ds = dq/T = 0$,

$$0 = dq = c_P dT - \frac{\delta}{\rho} dP, \qquad \text{(A. 29)}$$

and with $(dT/dP)_s = \delta/\rho c_P$,

$$\nabla_{\rm ad} \equiv \left(\frac{P}{T}\frac{dT}{dP}\right)_s = \frac{P\delta}{T\rho c_P}. \qquad \text{(A. 30)}$$

A non-stationary shell can change its internal energy, and it can exchange mechanical work (PdV) with the neighbouring shells. Then (A. 19) can be rewritten as

$$dq = \left(\varepsilon - \frac{\partial l}{\partial m}\right) dt. \qquad \text{(A. 31)}$$

With (A. 20),

$$\frac{\partial l}{\partial m} = \varepsilon - \frac{\partial u}{\partial t} - P\frac{\partial v}{\partial t} = \varepsilon - \frac{\partial u}{\partial t} + \frac{P}{\rho^2}\frac{\partial \rho}{\partial t}, \qquad \text{(A. 32)}$$

where

$$v = \frac{1}{\rho}, \qquad \text{(A. 33)}$$

$$\frac{\partial v}{\partial t} = -\frac{1}{\rho^2}\frac{\partial \rho}{\partial t}. \qquad \text{(A. 34)}$$

It can be rewritten as

$$\frac{\partial l}{\partial m} = \varepsilon - c_P\frac{\partial T}{\partial t} + \frac{\delta}{\rho}\frac{\partial P}{\partial t}. \qquad \text{(A. 35)}$$

We define a source function $\varepsilon_{\rm g}$

$$\varepsilon_{\rm g} = -T\frac{\partial s}{\partial t} = -c_P\frac{\partial T}{\partial t} + \frac{\delta}{\rho}\frac{\partial P}{\partial t}. \qquad \text{(A. 36)}$$

Then we consider the neutrino losses. Stellar material is normally transparent to neutrinos and they can easily escape a star with the energy they have. ε_ν presents the energy loss per unit mass per second from the stellar material in the form of neutrinos.

$$\frac{\partial l}{\partial m} = \varepsilon - \varepsilon_\nu + \varepsilon_{\rm g}. \tag{A. 37}$$

Therefore

$$\frac{\partial l}{\partial m} = \varepsilon_{\rm n} - \varepsilon_\nu - c_p \frac{\partial T}{\partial t} + \frac{\delta}{\rho}\frac{\partial P}{\partial t}. \tag{A. 38}$$

A.1.4 Energy transfer

According to (A. 5),

$$\frac{\partial T}{\partial r} = 4\pi r^2 \rho \frac{\partial T}{\partial m}, \tag{A. 39}$$

and we can write as

$$\frac{\partial T}{\partial m} = -\frac{1}{k_{\rm rad}}\frac{l}{4\pi r^2}\frac{1}{4\pi r^2 \rho}, \tag{A. 40}$$

where $k_{\rm rad}$ represents the coefficient of conduction for the radiative transport. The coefficient $k_{\rm rad}$ can be written as

$$k_{\rm rad} = \frac{4ac}{3}\frac{T^3}{\kappa\rho}, \tag{A. 41}$$

where κ is a mean absorption coefficient, i.e. a radiative cross-section per unit mass averaged over frequency and a is the radiation-density constant ($= 7.57\times10^{-15}$erg cm^{-3}K^{-4}). The energy density of radiation U can be written as

$$U = aT^4, \tag{A. 42}$$

$$\frac{\partial U}{\partial r} = 4aT^3 \frac{\partial T}{\partial r}. \tag{A. 43}$$

With (A. 40), the basic equation for radiative transport of energy is obtained as

$$\frac{\partial T}{\partial m} = -\frac{3}{64\pi^2 ac}\frac{\kappa l}{r^4 T^3}. \tag{A. 44}$$

Assuming hydrostatic equilibrium, we obtain with (A. 13) and (A. 44)

$$\frac{(\partial T/\partial m)}{(\partial P/\partial m)} = \frac{3}{16\pi acG}\frac{\kappa l}{mT^3}. \tag{A. 45}$$

In a star in hydrostatic equilibrium and transporting the energy by radiation, the ratio of the derivatives $(dT/dP)_{\rm rad}$ is a gradient describing the temperature variation with depth.

$$\nabla_{\rm rad} = \left(\frac{d\ln T}{d\ln P}\right)_{\rm rad}. \tag{A. 46}$$

We can rewrite (A. 45) as

$$\nabla_{\rm rad} = \frac{3}{16\pi acG}\frac{\kappa l P}{mT^4}. \tag{A. 47}$$

$\nabla_{\rm rad}$ means a spatial derivative connecting P and T in two neighbouring mass shells, while $\nabla_{\rm ad}$ describes the thermal variation of one and the same mass element during its adiabatic compression. For hydrostatic equilibrium and for transport by radiation, we can set the real temperature gradient ∇ as $\nabla = \nabla_{\rm rad}$. The equation (A. 47) can be rewitten as

$$\frac{\partial T}{\partial m} = -\frac{GmT}{4\pi r^4 P}\nabla. \tag{A. 48}$$

For convection in the very deep stellar interior, $\nabla = \nabla_{\rm ad}$.

A.1.5 Chemical evolution

Next, we consider a very important concept, the chemical composition. The nuclear reactions are directly influenced by it as absorption of radiation or generation of energy. The composition of stellar matter is extremely simple because of the high temperatures and pressures. In the stellar interior, there are no chemical compounds and the atoms are completely ionized for the most part. We introduce the fraction of a unit mass X_i, which consists of nuclei of type i. It requires that

$$\sum_i X_i = 1, \tag{A. 49}$$

$$X_i = \frac{m_i n_i}{\rho}, \tag{A. 50}$$

where n_i is the particle number per volume with mass m_i. For many purposes it is even sufficient to specify only the mass fractions of hydrogen, helium, and the rest with the notations X, Y, Z, respectively.

$$X \equiv X_{\rm H}, \qquad Y \equiv X_{\rm He}, \qquad Z \equiv 1 - X - Y. \tag{A. 51}$$

Nuclear reactions will eventually change the rate of chemical component.

In radiative regions, there is no exchange of matter between different mass shells, if we can neglect diffusion. The X_i can change only if nuclear reactions create or destroy nuclei of type i in the mass element.

The frequency of a certain reaction is described by the reaction rate r_{lm}; the number of reactions per unit volume and time that transform nuclei from type l into type m. In general an element i can be affected simultaneously by many reactions, some of which create it (r_{ji}) and some of which destroy it (r_{ik}). These reaction rates gives directly the change per second of n_i. With (A. 50), we can write

$$\frac{\partial X_i}{\partial t} = \frac{m_i}{\rho}\left(\sum_j r_{ji} - \sum_k r_{ik}\right), i = 1, \ldots, I, \tag{A. 52}$$

for any of the element $1, \ldots, I$ which are involved in reactions.

A.2 Timescales

A.2.1 Dynamical time-scale

If the pressure term in (A. 17) suddenly disappears, the inertial term on the left would then have to compensate only the gravitational term on the right. We define a characteristic time-scale $\tau_{\rm ff}$ for the ensuing collapse of the star by setting $|\ \partial^2 r/\partial t^2\ | = R/\tau_{\rm ff}^2$. Then we obtain from (A. 17),

$$\tau_{\rm ff} \approx \left(\frac{R}{g}\right)^{1/2}. \tag{A. 53}$$

This is some kind of a mean value for the free fall time over a distance of order R following the sudden disappearance of the pressure. We can correspondingly determine a time-scale $\tau_{\rm expl}$ for the explosion of our star for the case that gravity were suddenly to disappear: $R/\tau_{\rm expl}^2 = P/\rho R$, where we have replaced $\partial P/\partial r$ by P/R after writing $4\pi r^2\,(\partial P/\partial m) = (\partial P/\partial r)\,/\rho$ (P and ρ are here average values over the entire star). We then find that

$$\tau_{\rm expl} \approx R\left(\frac{\rho}{P}\right)^{1/2} = \frac{R}{\left(\frac{P}{\rho}\right)^{\frac{1}{2}}}. \tag{A. 54}$$

Since $(P/\rho)^{1/2}$ is one of the order of the mean velocity of sound in the stellar interior, one can see that $\tau_{\rm expl}$ is one of the order of the time a sound wave needs to travel from the center to the surface.

If this model is near hydrostatics equilibrium, then the two terms on the right side of (A. 17) have nearly equal absolute values and $\tau_{\rm ff} \approx \tau_{\rm expl}$. We then call this time-scale the hydrostatic time-scale $\tau_{\rm hydr}$, since it gives the typical time in which a dynamically stable star reacts on a slight perturbation of hydrostatic equilibrium. With $g = GM/R^2$, we obtain from (A. 53) up to factors of order 1 that

$$\tau_{\rm hydr} \approx \left(\frac{R^3}{GM}\right)^{1/2} \approx \frac{1}{2}\,(G\bar{\rho})^{-1/2}, \tag{A. 55}$$

where $\bar{\rho}$ is the mean mass density. For the sun, we estimate $\tau_{\rm hydr} \approx 27$ minutes. In the most phases of stellar evolution, the stars change on a much longer time-scale than $\tau_{\rm hydr}$. Then they are very close to hydrostatic equilibrium and the inertial terms in (A. 17) can be ignored.

A.2.2 Kelvin-Helmholtz time-scale (thermal time-scale)

According to (A. 72) obtain below (see Section A.3), L is of the order of $|\ dE_{\rm g}/dt\ |$, we can define a characteristic time-scale, the Kelvin-Helmholtz time-scale.

$$\tau_{\rm KH} = \frac{|\ E_{\rm g}\ |}{L} \approx \frac{E_{\rm i}}{L}, \tag{A. 56}$$

$$|\ E_{\rm g}\ | \approx \frac{GM^2}{2R}, \tag{A. 57}$$

where $E_{\rm i}$ and $E_{\rm g}$ are the total internal energy and the total gravitational energy of the star, respectively. Then we can write

$$\tau_{\rm KH} \approx \frac{GM^2}{2RL}. \tag{A. 58}$$

For the sun, we estimate $\tau_{\rm KH} \approx 1.6 \times 10^7$ years.

A.2.3 Nuclear time-scale

If we consider a star balancing its energy loss L remaining constant by release of nuclear energy E_n, the nuclear time-scale τ_n can be defined as

$$\tau_n = \frac{E_n}{L}. \tag{A. 59}$$

E_n is the energy reservoir from released energy by nuclear reactions. The most important reaction is the fusion of ^{1}H into ^{4}He. The net result of hydrogen burning is the fusion of four ^{1}H nuclei into one ^{4}He nucleus. The difference in binding energy is 26.731 MeV corresponding to the mass defect of 0.71 per cent. This hydrogen burning releases $Q = 6.3 \times 10^{18}$erg g^{-1} and if the sun consisted of hydrogen completely, E_n would be $QM_\odot = 1.25 \times 10^{52}$ erg. With $L_\odot = 4 \times 10^{33}$erg s^{-1}, (A. 59) gives $\tau_n = 3 \times 10^{18}$s or 10^{11} years.

Compared with the τ_{hydr} and τ_{KH}, it shows

$$\tau_n \gg \tau_{KH} \gg \tau_{hydr}. \tag{A. 60}$$

A.3 Virial theorem

The virial theorem connects two important energy reservoirs of a star and allows predictions and interpretations of certain evolutionary phases. If we multiply (A. 13) by $4\pi r^3$ and integrate over dm in the interval $[0, M]$, that is from center to surface, we obtain on the left-hand side an integral which can be simplified by partial integration:

$$\int_0^M 4\pi r^3 \frac{\partial P}{\partial m} dm = \left[4\pi r^3 P\right]_0^M - \int_0^M 12\pi r^2 \frac{\partial r}{\partial m} P dm, \tag{A. 61}$$

where the term in brackets vanishes, since $r = 0$ at the center and $P = 0$ at the surface. After multiplication by $4\pi r^3$ and integration, (A. 13) gives

$$-\int_0^M \frac{Gm}{r} dm = -3 \int_0^M \frac{P}{\rho} dm. \tag{A. 62}$$

Both sides of (A. 62) have the dimensions and we define the *gravitational energy* E_g by

$$E_g = -\int_0^M \frac{Gm}{r} dm. \tag{A. 63}$$

Considering a unit mass at the position r, its potential energy due to the gravitational field of the mass m inside r is $-Gm/r$. Therefore E_g is the potential energy of all mass elements dm of the star, normalized to zero at infinity.

In order to understand the meaning of the term on the right side of (A. 62), we assume an ideal gas. Then

$$\frac{P}{\rho} = \frac{\mathfrak{R}}{\mu} T = (c_P - c_v)\, T = (\gamma - 1)\, c_v T, \tag{A. 64}$$

where $c_P - c_v$ are the specific heats per unit mass, $\mathfrak{R}$ is the gas constant ($\mathfrak{R} = 8.315 \times 10^7$erg K^{-1}g^{-1}) and μ is the dimensionless mean molecular weight. We use $\mathfrak{R}/\mu = c_P - c_v$ and replace c_P/c_v by γ. For a monatomic gas, $\gamma = 5/3$, and we have

$$\frac{P}{\rho} = \frac{2}{3} u. \tag{A. 65}$$

$u = c_v T$ is the internal energy per unit mass of the ideal gas. (A. 62) can be rewritten with the total internal energy of the star:

$$E_\mathrm{i} = \int_0^M u dm, \tag{A. 66}$$

as

$$E_\mathrm{g} = -2E_\mathrm{i}. \tag{A. 67}$$

This equation is called the *verial theorem* for an ideal monatomic gas. We introduce a quantity ζ for a general equation of state.

$$\zeta u = 3\frac{P}{\rho}. \tag{A. 68}$$

For an ideal gas, $\zeta = 3(\gamma - 1)$. In the monatomic gas, $\gamma = 5/3$ and $\zeta = 2$. If ζ is constant throughout the star, (A. 62) becomes more general verial theorem:

$$\zeta E_\mathrm{i} + E_\mathrm{g} = 0. \tag{A. 69}$$

Total energy W can be written as

$$W = E_\mathrm{i} + E_\mathrm{g}. \tag{A. 70}$$

For a gravitationally bound system $W < 0$,

$$W = (1 - \zeta)\, E_\mathrm{i} = \frac{\zeta - 1}{\zeta} E_\mathrm{g}. \tag{A. 71}$$

In the case of $\zeta = 1\,(\gamma = 4/3)$ the total energy vanishes.

The luminosity of the star L is the total energy loss par unit time by radiation, $L = -dW/dt$. With (A. 71), we obtain

$$L = (\zeta - 1)\,\frac{dE_\mathrm{i}}{dt} = -\frac{\zeta - 1}{\zeta}\frac{dE_\mathrm{g}}{dt}. \tag{A. 72}$$

B. Stages of stellar evolution

B.1 Star formation

Stars are formed by the collapse of interstellar clouds. For an infinite homogeneous gas at rest, the density and temperature are constant everywhere. For symmetry reasons, the gravitational potential Φ must be also constant. The gas obeys the equation of motion of hydrodynamics

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla)\, \mathbf{v} = -\frac{1}{\rho}\nabla P - \nabla \Phi, \tag{B. 1}$$

and the continuity equation

$$\frac{\partial \rho}{\partial t} + \mathbf{v}\nabla\rho + \rho\nabla \cdot \mathbf{v} = 0. \tag{B. 2}$$

We can use the Poisson's equation

$$\nabla^2\Phi = 4\pi G\rho, \tag{B. 3}$$

and the equation of state for an ideal gas

$$P = \frac{\Re}{\mu}\rho T = v_s^2\rho, \tag{B. 4}$$

where v_s is the isothermal speed of sound. For equilibrium, we assume $\rho = \rho_0 =$ constant, $T = T_0 =$ constant, and $v_0 = 0$. By boundary condition at infinity, the gravitational potential Φ can be determined as

$$\nabla^2\Phi_0 = 4\pi G\rho_0. \tag{B. 5}$$

Next, we perturb the equilibrium

$$\rho = \rho_0 + \rho_1, \qquad P = P_0 + P_1, \qquad \Phi = \Phi_0\Phi_1, \qquad \mathbf{v} = \mathbf{v}_1, \tag{B. 6}$$

where the function with subscript 1 depend on space and time. If the perturbations are isothermal and we ignore non-linear terms in these quantities, we find

$$\frac{\partial \mathbf{v}_1}{\partial t} = -\nabla\left(\Phi_1 + v_s^2\frac{\rho_1}{\rho_0}\right), \tag{B. 7}$$

$$\frac{\partial \rho_1}{\partial t} + \rho_0\nabla\cdot\mathbf{v}_1 = 0, \tag{B. 8}$$

$$\nabla^2\Phi_1 = 4\pi G\rho_1. \tag{B. 9}$$

It is a linear homogeneous system of differential equations with constant coeffients. If solutions exist with the space and time dependence proportional to $\exp[i(kx + \omega t)]$,

$$\frac{\partial}{\partial x} = ik, \qquad \frac{\partial}{\partial y} = \frac{\partial}{\partial z} = 0, \qquad \frac{\partial}{\partial t} = i\omega. \tag{B. 10}$$

With $v_{1x} = v_1, v_{1y} = v_{1z} = 0$, we find

$$\omega v_1 + \frac{k v_s^2}{\rho_0}\rho_1 + k\Phi_1 = 0, \tag{B. 11}$$

$$k\rho_0 v_1 + \omega\rho_1 = 0, \tag{B. 12}$$

$$4\pi G\rho_1 + k^2\Phi_1 = 0. \tag{B. 13}$$

Assuming a non-vanishing wave number k, we obtain

$$\omega^2 = k^2 v_s^2 - 4\pi G\rho_0. \tag{B. 14}$$

In the limit $k \to \infty$, (B. 14) gives $\omega^2 = k^2 v_s^2$. It corresponds to isothermal sound waves. For very short waves, gravity is not important, any compression is restored by increased pressure and the perturbations travel with the speed of sound through space. If $k^2 > 4\pi G\rho_0/v_s^2$, the eigenvalue ω is of the form $\pm i\xi$, where ξ is real. Therefore there exist perturbations $\sim \exp(\pm\xi t)$ which grow exponentially with time, so that the equilibrium is unstable. If we define a characteristic wave number k_J as

$$k_J^2 = \frac{4\pi G\rho_0}{v_s^2}, \quad \text{(B. 15)}$$

or

$$\lambda_J = \frac{2\pi}{k_J}, \quad \text{(B. 16)}$$

perturbations are unstable, with a wave number $k < k_J$ or a wavelength $\lambda > \lambda_J$. The condition for instability $\lambda > \lambda_J$, where

$$\lambda_J = \left(\frac{\pi}{G\rho_0}\right)^{1/2} v_s, \quad \text{(B. 17)}$$

is called the Jeans criterion.

For the case of perturbations instability, gravity overcomes pressure and it collapses. In (B. 14), we estimate ω only from the gravitational term and we have $i\omega \approx (G\rho_0)^{1/2}$. The corresponding time-scale is free-fall time defined as $\tau \approx (G\rho_0)^{1/2}$. With $\rho_0 = 4 \times 10^{-23}$g cm^{-3} corresponding to a slightly enhanced interstellar density, we obtain the free-fall time $\approx 10^7$ years.

When the Jeans criterion is fulfilled, a gaseous mass has become unstable, the collapse has started, and gravity increases relatively more than pressure gradient. Before the mass becomes a point, the pressure will become relevant as the gas becomes opaque and T increases. Then the free-fall has to be abandoned and finally the collapse will be stopped.

We assume here numerically the unstable interstellar cloud of one solor mass with $R = 1.63 \times 10^{17}$ cm and with $\rho = 10^{-19}$g cm^{-3}, and the mass fractions of hydrogen, helium and heavier elements are taken to be $X = 0.651, Y = 0.324$, and $Z = 0.025$. The collapse of the homogeneous central part resembles a free fall as long as the matter can get rid of the released gravitational energy via radiation. The central regions becomes opaque once a central density of 10^{-13}g cm^{-3} is reached. The further increase of density in the center causes an adiabatic increase of temperature. As a consequence the pressure there increases until the free fall is stopped. It leads to the formation of a central core in hydrostatic equilibrium its mass and radius are 10^{31} g and 6×10^{13} cm, and the central values are $\rho_c = 2 \times 10^{-10}$gcm^{-3} , $T_c = 170$ K. The free-fall velocity at the surface of the core is 75 km/s. With increasing core mass and decreasing core radius, the velocity of the falling material exceeds the velocity of sound in the core surface regions. Therefore a spherical shock front is formed which separates the supersonic rain from the hydrostatic interior. In this shock front the falling matter comes to rest, releasing its kinetic energy. In certain respects the hydrostatic core resembles a star. Since gravitational energy is released in the deep interior of the core during contraction, there must be a finite temperature gradient in order to transport this energy outward. The accreting core in hydrostatic equilibrium is often called a protostar. The accreating protostar heats up in its interior. At low temperature, the gas consists in molecular form as H_2. When the central temperature reaches about 2000 K, the hydrogen molecules dissociates. When almost all hydrogen in the central region is in atomic form, the collapsing protostar forms a dynamically stable subcore in its interior. This core has an initial mass of $1.5 \times 10^{-3} M_\odot$ and initial radius of 1.3 $R_\odot$. Its central density is 2×10^{-2}g cm^{-3} and central temperature is 2×10^4 K. Defining an effective radius R at the optical depth $\tau = 2/3$, one can derive an effective temperature T_{eff} from $L = 4\pi R^2 \sigma T_{\text{eff}}^4$ where σ is Stefan-Boltzmann constant. To an outside observer the collapsing cloud remains an infrared object as long as the envelope is opaque to visible radiation. With decreasing radius of the photosphere ($\tau = 2/3$), T_{eff} must increase in order to radiate away the energy. In the whole first phase, the luminosity is produced by accretion.

On the Hayashi line, we have the transition from a protostar to a normal contraction star in quasi-hydrostatic, but not yet in thermal, equilibrium.

B.2 Pre-main-sequence phase

A star which has not yet reached the temperature for nuclear burning has to supply its energy loss by contraction. This is a consequence of the virial theorem and of energy conservation. A part of the released gravitational energy goes into internal energy, while the rest supplies the luminosity (see (A. 72)). The characteristic time-scale is τ_{KH}.

According to homologous contraction, the variation of the central temperature dT_c, is related to the variation of the central density, $d\rho_c$ by

$$\frac{dT_c}{T_c} = \frac{4\alpha - 3}{3\delta}\frac{d\rho_c}{\rho_c}. \tag{B. 18}$$

The slope depends on the equation of state via α and δ. For an ideal gas, $\alpha = \delta = 1$ and (B. 18) becomes

$$\frac{dT_c}{T_c} = \frac{1}{3}\frac{d\rho_c}{\rho_c}. \tag{B. 19}$$

In this case, the slope is 1/3 and a contracting ideal gas heats up. In the limit of complete non-relativistic degeneracy, one has $\alpha \to 3/5$ and $\delta \to 0$. When the sphere is contracting and becomes more and more degenerate, and δ is still finite α will exceed the value 3/4 and the slope given in (B. 18) will change sign. Further contraction leads to cooling. The stellar center tends to cool off at almost constant density. In the case of complete relativistic degeneracy, with $\alpha = 3/4$ and $\delta = 0$, the factor on the right side of (B. 18) becomes indeterminate and the ion gas will determine the slope.

If stellar mass is too large, the evolution is not remarkably influenced by degeneracy and the center continuously heats up during the contraction. The less massive spheres will finally be forced by degeneracy to cool off after having reached a maximum central temperature, and consequently a homologous contraction can not bring the central temperature above a few 10^7 K which is not sufficient to start nuclear reaction. The hydrogen burning occurs at a characteristic temperature near 10^7 K, helium burning at 10^8 K.

According to computer calculations, protostars of mass less than about $0.08 M_\odot$ never ignite their hydrogen and never become main-sequence stars. Such objects are called *black or brown dwarfs*. Too little massive protostars never reach the state of complete equilibrium by which the main-sequence models are defined. They release their energy due to contraction by infrared radiations.

The contracting star more than 0.08 $M_{\odot}$ ignites hydrogen in the center and becomes a star on the zero-age main sequence (ZAMS). While the luminosity of the star was originally due to contraction, now it originates from nuclear energy. The stars approach to the ZAMS in the Kelvin-Helmholtz time-scale. In the Hertzsprung-Russel diagrams of very young stellar clusters, for example NGC 2264 and the Pleiades (M45), one finds only massive stars are on the main sequence, while the low-mass stars lie to the right of it. Because of their longer $\tau_{\rm KH}$, these stars are still in the contraction phase and have not yet begun with nuclear burning. Among them, there are flare stars (some sort of UV Ceti stars) and T Tauri variables.

B.3 Main-sequence phase

In the main-sequence phase, the large energy losses from the stellar surface producted by hydrogen burning. These reactions release nuclear binding energy by converting hydrogen into helium. This chemical evolution of the star concerns primarily the central region, since the energy sources are strongly concentrated towards the center.

For stars with up to 1.3 $M_{\odot}$, the main nuclear reaction occurs in the form of the proton-proton chain (pp chain). The reaction networks are

pp I	$^{1}\mathrm{H} + {}^{1}\mathrm{H} \to {}^{2}\mathrm{D} + e^{+} + \nu$
	$^{1}\mathrm{H} + {}^{1}\mathrm{H} + e^{-} \to {}^{2}\mathrm{D} + \nu$
	$^{2}\mathrm{D} + {}^{1}\mathrm{H} \to {}^{3}\mathrm{He} + \gamma$
	$^{3}\mathrm{He} + {}^{3}\mathrm{He} \to {}^{4}\mathrm{He} + {}^{1}\mathrm{H} + {}^{1}\mathrm{H}$
pp II	$^{3}\mathrm{He} + {}^{4}\mathrm{He} \to {}^{7}\mathrm{Be} + \gamma$
	$^{7}\mathrm{Be} + e^{-} \to {}^{7}\mathrm{Li} + \nu$
	$^{7}\mathrm{Li} + {}^{1}\mathrm{H} \to {}^{4}\mathrm{He} + {}^{4}\mathrm{He}$
pp III	$^{7}\mathrm{Be} + {}^{1}\mathrm{H} \to {}^{8}\mathrm{B} + \gamma$
	$^{8}\mathrm{B} \to {}^{8}\mathrm{Be} + e^{+} + \nu$
	$^{8}\mathrm{Be} \to {}^{4}\mathrm{He} + {}^{4}\mathrm{He}$.

The energy given with a minus sign is the average energy lost as neutrinos.

In the Sun, the pp I reaction network contributes about 85 % of the luminosity, pp II about 15 %, and pp III only about 0.015 %.

For stars with masses above 1.2 $M_{\odot}$, the CNO cycle dominates. The reaction network is

$^{12}\mathrm{C} + {}^{1}\mathrm{H} \to {}^{13}\mathrm{N} + \gamma$

$^{13}\mathrm{N} \to {}^{13}\mathrm{C} + e^{+} + \nu$

$^{13}\mathrm{C} + {}^{1}\mathrm{H} \to {}^{14}\mathrm{N} + \gamma$

$^{14}\mathrm{N} + {}^{1}\mathrm{H} \to {}^{15}\mathrm{O} + \gamma$

$^{15}\mathrm{O} \to {}^{15}\mathrm{N} + e^{+} + \nu$

$^{15}\mathrm{N} + {}^{1}\mathrm{H} \to {}^{12}\mathrm{C} + {}^{4}\mathrm{He}$

$^{15}N + {}^{1}H \rightarrow {}^{16}O + \gamma$
$^{16}O + {}^{1}H \rightarrow {}^{17}F + \gamma$
$^{17}F \rightarrow {}^{17}O + e^{+} + \nu$
$^{17}O + {}^{1}H \rightarrow {}^{14}N + {}^{4}He$.

The stars with the pp chain reaction have a radiative core and a convective envelope. In the absence of mixing, the change of X_H at any given mass element is proportional to the local value of ε_H, $\Delta X_H \sim \varepsilon_H \Delta t$. Interior composition profile shows the gradual exhaustion of hydrogen in the star. At the end of the main-sequence phase, $X_H \rightarrow 0$ in the center.

Contrarily, the stars that the CNO cycle dominates have a convective core and a radiative envelope. The helium production is even more concentrated towards the center because of the large sensitivity to temperature of the CNO cycle. The mixing inside the central convective core is so rapid compared to the local production of new nuclei that the core is homogeneous at any time. Inside the core, $\Delta X_H \sim \bar{\varepsilon}_H \Delta t$ with an energy production rate $\bar{\varepsilon}_H$ averaged over the whole core. At the end of central hydrogen burning, the star has a helium core with $M_{He} \approx 0.1M$, and a envelope in which X_H still has almost original value.

The time a star spends on the main sequence while it burns its central hydrogen corresponds the nuclear time-scale and it depends on M because the luminosity L increases so strongly with $M(L \sim M^{3.5})$.

B.4 Helium burning

B.4.1 Massive stars

At the end of hydrogen burning, the star is left with a helium core without nuclear energy release surrounded by a hydrogen-rich envelope. After a short resettling at the end of central hydrogen burning, the core contracts and the layers above expands. The compression of the core would be accompanished by a large jump in the HR diagram, from the main sequence to the region of the Hayashi line.

In the contracting core $\varepsilon_g > 0$, and $\varepsilon_g < 0$ in the expanding envelope. The energy released in the core must flow outwards, which prevents the core from becoming isothermal. The contraction of the core leads to heating and when the central temperature has reached about 10^8 K, helium is ignited. Then the core stops its rapid contraction and the star again reaches a stage of complete thermal and hydrostatic equilibrium. The whole core contraction has proceeded on the Kelvin-Helmholtz time-scale. On the same time, the envelope have rapidly expanded and the star transforms into a red giant so rapidly. There is little chance to observe it during this short phase of evolution. This area between main sequence and red giants is well-known as *Hertzsprung gap*.

For the stars with $2.5M_\odot < M$, central helium burning is ignited before the core becomes degenerate. Then, the star is in the red-giant region of the HR diagram, close to the Hayashi line and it has a very deep outer convection zone. The reactions of helium burning consist of the gradual fusion of several ^{4}He into ^{12}C, ^{16}O, $\cdots$ and it requires higher temperatures of 10^8

K than that of hydrogen burning, because of the high Coulomb barriers. The first reaction is the formation of ^{12}C from three ^{4}He nuclei called the *triple alpha (3α) reaction*.

$^{4}He + ^{4}He \rightleftharpoons ^{8}Be$

$^{8}Be + ^{4}He \rightarrow ^{12}C + \gamma$

$^{12}C + ^{4}He \rightarrow ^{16}O + \gamma$

$^{16}Be + ^{4}He \rightarrow ^{20}Ne + \gamma$.

Althought the specific gain of energy is only 1/10 comparing with hydrogen burning, the phase of central helium burning lasts about 20% of the duration of the main-sequence phase. Because most of the total energy output in this phase comes from hydrogen shell burning. The release of nuclear energy inside the core stops the contraction and brings the whole star nearly into thermal equilibrium. For the intermediate mass ($2.5 \sim 7\,M_{\odot}$) stars, after central helium burning is ignited, the star moves far to the left on the HR diagram. The bluest point is reached after 75 % of the helium burning phase when the central helium content is down. The track then leads back toward the vecinity of the Hayashi line. It indicates the ends of the central helium burning. Large loops are obtained for stars with large mass. With decreasing M the loops become gradually smaller and finally degenerate to a mere down and up along the Hayashi line.

This loop is necessary for explaining the observed δ Cephei variables. The observations show that these stars are giants located in the HR diagram in a narrow strip roughly parallel to the Hayashi line and a few 10^2 K wide. A star is unstable if it is located in the instability strip of the HR diagram, where the observed Cepheids are found. In this phase, the outer stellar envelope particularly the helium ionization zone reacts on small perturbations. When a stellar model has evolved into the instability strip, the oscillation will grow to finite, observable amplitudes. The evolutionary tracks discussed above cross the instability strip up to three times. For all stars a first crossing occurs in the phase of hydrogen core contraction, however this passage is so rapid that there is scarcely a chance for observation as a Cepheid. We can observe it at second and third passages which occur only for sufficiently large loops.

The theory of stellar pulsations also gives the period Π of the oscillation. Π is shown to depend only on the mean density $\bar{\rho}$ of the whole star as

$$\Pi\sqrt{\bar{\rho}} = constant, \qquad \bar{\rho} \sim M/R^3 \qquad \text{(B. 20)}$$

Π is of the order of the hydrostatic time-scale $\tau_{\rm hydr}$. During a passage through the Cepheid strip from right to left, the radius R decreases. It means that Π also decrease. During a passage in the opposite direction, the period Π will increase.

Like these classical Cepheids, we can find the RR Lyrae stars of much smaller mass located on the horizontal branch of the HR diagram. The branch intersect the downward continuation of the instability strip. Even further down in the HR diagram, in the region of the main sequence, the instability strip is marked by δ Scuti stars or dwarf Cepheids. These palsating stars are driven by κ mechanism. In the near-surface layers of a star with an effective temperature of about 5000 K, there are two regions where ionization, together with a suitable form of the function $\kappa = \kappa(P, T)$, acts in the direction of instability. The outer one is the close to the surface, where hydrogen is partially ionized, followed immediately by the first ionization of helium.

Ionization reduces ∇_{ad} (for a monatomic gas, it has 0.4) appreciably. Below this ionization zone, ∇_{ad} goes back to its standard value of 0.4. But still deeper another region of excitation occurs caused by the second ionization of helium. This region contributes most to instability. Energy is stored in the form of the second ionization of helium during the compression stage of the cycle and then released the helium recombination during the expansion stage. The restriction of Cepheid pulsations to stars in a limited temperature range follows from the requirement that the second helium ionization zone lies near the transition from the nearly adiabatic interior, where any driving is almost canceled by an equal amount of damping, to the non-adiabatic exterior where the thin outer layers lack the heat capacity to modulate the outward flow of radiation.

In the central core, helium burning terminates when ^{4}He is completely processed to ^{12}C, ^{16}O, and ^{20}Ne (the ratio depends on the temperatures, i.e., on the stellar mass and on the reaction rates). The burning continues in a concentric shell surrounding the exhausted core. While the helium shell burns outwards, the C-O core increases in mass and contracts. The situation resembles that before central helium burning. In this phase, the star has two shell sources, since the hydrogen shell is still burning at the bottom of the hydrogen-rich envelope. The core contracts, the helium region between the two shell sources expands, and the envelope contracts. In the HR diagram, the point of star moves to the left. Then, the temperature in the hydrogen shell source drops so far that hydrogen burning ceases. The outer of the two shell sources has disappeared and core contraction is accompanied by expansion of all layers above helium-burning shell. On the HR diagram, it moves to the right and upwards. The luminosity increases strongly with increasing mass of the C-O core. The outer convective envelope gradually reaches further down until it contains more than 80 % of the stellar mass. The nuclei ^{12}C, ^{16}O are dredged up by the outer convection zone and can appear at the surface.

B.4.2 Low-mass stars

Low-mass (typically $M < 2.3M_{\odot}$) main-sequence stars have small or no convective cores, and before central helium burning is ignited, the core becomes degenerate. These stars in this phase have large central density ($\geq 10^2$ g cm^{-3}) where electron gas is at the border of degeneracy. The stars can exist in thermal equilibrium with a degenerate, isothermal helium core.

Central hydrogen burning is switched to shell burning, and in the HR diagram, the star moves upwards and to the right. The luminosity grows with increasing core mass. The track is very close to the Hayashi line leading up along the ascending giant branch to higher luminosity and correspondingly larger radii.

Numerical calculations show that with growing core mass the temperature in the core rises. Controlled by the growth of core mass, the core temperature finally increase to $\approx 10^8$ K at which helium is ignited. It happens when the core mass $\approx 0.45M_{\odot}$, independent to the total stellaar mass. The onset of helium burning in the degerate core is unstable and results in a thermal runaway. During the thermal runaway, the central temperature is rising and the matter neither expands nor contracts. Since in the fully degenerate gas, the pressure does not depend on temperature and therefore the central density remains constant. But only an increase of pressure can lift the weight of the mass above and cause an expansion. During the thermal runaway, there is an enormous overproduction of nuclear energy and local luminosity comes up during a few seconds. It is called helium flash. However, almost nothing reaches the surface, since it is absorbed by expansion of the non-degenerate layer above.

With increasing temperature at constant density, the degeneracy is finally removed. With further increase of T, the core expands. With the removal of degeneracy, central helium burning becomes stable and the expansion stops the increase of temperature. After the violent phase of the helium flash, there follows a phase of quiet burning in non-degenerate matter. Low mass stars with non-degenerate helium burning core and a hydrogen envelope resulting from a helium flash, are located near the line in the HR diagram called the horizontal giant branch. After the helium has been exhausted, the phase of rapid core contraction starts and lasts until helium shell ignition. The mass of the helium core grows owing to hydrogen-shell burning, while in the inner convective shell, helium is consumed and carbon and oxygen are produced. Nuclear burning takes place in two shell (hydrogen and helium burning). The stars take positions in upper horizontal branch and arrive on the asymptotic giant branch (AGB).

After the hydrogen shell has burned outward for some time, the temperature in this shell drops and hydrogen-shell burning extinguished. Although the layer of transition between the hydrogen-rich envelope and the helium region stays at a fixed value of m, there is still active helium-burning shell moving to higher values of m and approaching the bottom of the hydrogen-rich envelope. Since helium burning proceeds at a temperature of $\geq 10^8$ K, hydrogen burning starts again. In this phase, shell burning becomes secularly unstable, resulting in a thermal runaway. It leads to a cyclic phenomenon known as thermal pulses reoccurring within some 10^5 years. In the case of low-mass stars, the luminosity and the surface temperature can vary with each pulse. However, the pulses do not influence the core. The C-O core increases the mass with repeating the pulses.

B.5 Later phases

After central helium burning, further evolution depends on the mass of the core. The more the star is massive, the more central temperature rises and higher burning is ignited. Finally the star is separated by mass shells of different chemical composition as an onion skin.

As is described in section B.2, protostars of mass less than about $0.08M_\odot$ never ignite their hydrogen and never become main-sequence stars. Such objects are called *black or brown dwarfs*.

For the stars with $M < 0.48M_\odot$, where M is the mass on the main sequence, the lifetime of the main sequence would be longer than the age of Universe. Consequently the oldest star with the smallest mass stays still on the main sequence. However, theoretically, for these stars, the temperature of helium core would not sufficiently large to ignite. The core continues to degenerate and finally the star would remain the degenerate helium core.

Stars with $0.48M_\odot \leq M \leq 8M_\odot$ evolve until central helium burning but carbon burning can not occur. After central helium burning, the C-O core increases the mass with repeating thermal pulses and degenerates. The luminosity increases along the AGB on the HR diagram. At the point that the luminosity is sufficiently large, the outer layer becomes unstable. Consequently the star becomes a Mira type variable and loses the hydrogen-rich envelope. The Mira type variables have lower surface temperature than Cepheid variables. The cause of pulsation of Mira type is considered that the effect of convection would be important. However, the understanding of convection is insufficient, so it has not be solved theoretically yet. It causes the radius of this star decreases and surface temperature increases. On the HR diagram, it moves to left. When the surface temperature increases above several 10^4 K, the star shines the ejected gaseous envelope. We can observe it as a planetary nebula. The central star contains a low-mass core rich in carbon and oxygen. It contracts slowly to the white dwarf stage. The central star of the planetary nebula first appears very hot and bright but then cools down toward the portion occupied by white dwarfs. The mass of the white dwarf might be no more than $\sim 0.7 M_\odot$, the rest of the mass having been ejected durning the helium shell flash outbursts that produced the gaseous envelope of the planetary nebula.

More massive stars ($8M_\odot < M$) evolve more rapidly and their thermonuclear reactions proceed further as the star becomes a red supergiant. Helium burning at the core proceeds beyond carbon and oxgen, continuing on to form the most stable of nuclei ^{56}Fe. These stars finally undergo explosions or collapse. Collapse and explosions are connected with supernova events.

B.6 Final explosions and collapse

For the mixture consisting mainly of ^{12}C and ^{16}O found in the stellar center after helium burning, carbon burning will set in if the temperature or the density rises sufficiently. The temperature for this burning is about 6×10^8 K.

$$\begin{aligned} {}^{12}\mathrm{C} + {}^{12}\mathrm{C} &\to {}^{24}\mathrm{Mg} + \gamma \\ &\to {}^{23}\mathrm{Mg} + n \\ &\to {}^{23}\mathrm{Na} + p \\ &\to {}^{20}\mathrm{Ne} + \alpha \\ &\to {}^{16}\mathrm{O} + 2\alpha. \end{aligned}$$

For oxygen burning, ^{16}O + ^{16}O, the Coulomb barrier is so high that the temperature needs higher than 10^9 K. As in the case of carbon burning, the reaction can proceed via several channels.

$$\begin{aligned} {}^{16}\mathrm{O} + {}^{16}\mathrm{O} &\to {}^{32}\mathrm{Si} + \gamma \\ &\to {}^{31}\mathrm{P} + p \\ &\to {}^{31}\mathrm{Si} + n \\ &\to {}^{28}\mathrm{Si} + \alpha \\ &\to {}^{24}\mathrm{Mg} + 2\alpha. \end{aligned}$$

For the temperature higher than 10^9 K, we have to consider the possibility of photodisintegration of nuclei that are not too strongly bound. Here the radiation field contains a significant number of photons with energies in the MeV range, which can be absorbed by a nucleus, breaking it up. For example, the neon disintegration occurs even before oxygen burning in stellar evolution.

$^{20}\mathrm{Ne} + \gamma \to {}^{16}\mathrm{O} + \alpha.$

The ejected α particle reacts mainly with other ^{20}Ne nuclei, yielding $^{24}\mathrm{Mg} + \gamma$. The net result will be the conversion of Ne into O and Mg.

$2^{20}\mathrm{Ne} \to {}^{16}\mathrm{O} + {}^{24}\mathrm{Mg} + \gamma.$

The photodisintegration of ^{28}Si is dominated reaction at the end of oxygen burning. Near $T = 3 \times 10^9$ K, ^{28}Si can be decomposed by the photons and eject n, p or α. It folllows a large number of reactions creating nuclei (Al, Mg, Ne etc.). They react with the remaining ^{28}Si, thus building up gradually heavier nuclei until ^{56}Fe is reached. The conversion of two ^{28}Si into ^{56}Fe is called silicon burning. For $T = 5 \times 10^9$ K, photodisintegration breaks up even the ^{56}Fe nuclei into α particles and reversed the effect of all prior burnings. Such processes can occur during supernova explosions.

For stars with $8M_\odot \leq M \leq 10M_\odot$, the core formed by degenerated O, Ne and Mg after carbon burning. When electron captures by Ne and Mg overcome oxygen burning, the pressure is reduced and a central collapse starts.

The stars with $10M_\odot \leq M$ have Fe core. The core contracts and becomes degenerate. When the central temperature exceeds 10^{10} K, photodisintegration occurs:

$^{56}\mathrm{Fe} \to 13^4\mathrm{He} + 4n - 124.4\ \mathrm{MeV},$

and the core collapses. This gravitational collapse leads a supernova event. The outer layer of the star ejected by the supernova event becomes supernova remnants.

For the star with $10M_\odot \leq M \leq 40M_\odot$, the core not ejected remains as a neutron star. The degenerate core having mass more than Chandrasekhar limit M_{Ch} becomes a neutron star.

For the star with $40M_\odot \leq M$, the mass of a collapsing core exceeds the mass limit of neutron star, a black hole, a object with very strong gravitational field, emerges.

The final phase of the star depends on the stellar mass.

C. Magnitude data in old star catalogues

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
2	And	—	—	—	—	—	—	5.78	5.10	3.7	A3Vn
3	And	—	—	—	—	—	—	5.11	4.65	0.2	K0III
4	And	—	—	—	—	—	—	5.78	5.33	−0.4	K5III
7	And	—	—	—	—	—	—	4.78	4.52	2.8	F0V
8	And	—	—	—	—	—	—	5.11	4.85	−1.1	M2III
9	And	—	—	—	—	—	—	5.78	6.02	—	A7m
11	And	—	—	—	—	—	—	5.78	5.44	0.2	K0III
12	And	—	—	—	—	—	—	5.78	5.70	3.4	F5V
13	And	—	—	—	—	—	—	5.78	5.75	−1.1	B9III
14	And	—	—	—	—	—	—	5.78	5.22	0.2	K0III
15	And	—	—	—	—	—	—	5.78	5.59	−0.4	A1III
18	And	—	—	—	—	—	—	5.45	5.35	−0.1	B9V
22	And	—	—	—	—	—	—	5.11	5.03	−2.0	F2II
23	And	—	—	—	—	—	—	5.78	5.72	1.7	F01V
28	And	—	—	—	—	—	—	5.45	5.24	0.5	A7III
32	And	—	—	—	—	—	—	4.78	5.33	0.3	G8III
39	And	—	—	—	—	—	—	5.78	5.98	1.8	A5m
41d	And	—	—	—	—	—	4.75	4.78	5.03	1.0	A3m
44	And	—	—	—	—	—	—	5.78	5.70	4.0	F8V
45	And	—	—	—	—	—	—	5.78	5.81	−1.3	B7III-IV
47	And	—	—	—	—	—	—	5.78	5.58	—	A1m
49A	And	5.08	5.24	5.23	—	—	—	5.78	5.27	0.2	K0III
51	And	3.75	3.91	3.57	—	—	—	—	3.57	−0.1	K3III
55	And	—	—	—	—	—	—	5.78	5.40	0.1	K1III
56	And	—	—	—	—	—	—	4.78	5.67	0.2	K0III
58	And	—	—	—	—	—	—	4.78	4.80	1.3	A5IV-V
59	And	—	—	—	—	—	—	5.78	6.10	1.2	A1Vn
60b	And	—	—	—	—	5.84	5.75	5.11	4.83	−0.5	K4III
62c	And	—	—	—	—	5.84	5.75	5.11	5.30	1.2	A1V
63	And	—	—	—	—	—	—	5.78	5.59	0.6	B9pSi
64	And	—	—	—	—	—	—	5.78	5.19	0.3	G8III
65	And	—	—	—	—	—	—	4.78	4.71	−0.2	K4III
α	And	2.41	2.24	2.23	1.81	1.84	1.75	1.78	2.06	−0.6	B9IV:p(HgMn)
β	And	3.08	2.24	2.23	1.81	1.84	1.75	2.11	2.06	0.2	M0IIIvar

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
γ	And	3.08	2.91	2.90	1.81	1.84	2.08	2.11	2.13	—	—
δ	And	3.08	3.24	3.23	2.81	2.84	2.75	3.11	3.28	−0.4	K3III
ε	And	4.08	3.91	3.90	3.81	3.84	3.75	3.78	4.37	—	G5IIIcomp
ζ	And	4.08	4.24	4.23	3.81	3.84	3.75	3.78	4.06	−2.4	KIII
η	And	4.08	4.58	4.57	4.81	3.84	4.08	4.78	4.42	1.5	G8III-IV
θ	And	4.08	4.24	4.23	3.81	3.84	4.08	4.45	4.60	1.4	A2V
ι	And	4.08	3.58	3.57	—	3.84	3.75	3.78	4.30	−0.5	B8V
κ	And	4.08	3.58	3.57	3.81	3.84	3.75	3.78	4.14	−0.3	B9IVn
λ	And	4.08	3.58	3.57	3.81	3.84	—	3.78	3.82	2.0	G8III-IV
μ	And	4.08	3.91	3.90	3.48	3.84	3.42	3.78	3.87	2.1	A5V
ν	And	4.08	4.24	4.23	3.81	3.84	3.75	4.11	4.52	−1.4	B5V
ξ	And	—	—	—	—	3.84	4.75	4.78	4.88	1.4	K0III-IV
o	And	3.08	3.91	3.57	—	3.84	3.08	3.45	3.62	—	B6IIIpe+A2p
π	And	4.08	3.91	3.90	4.81	4.84	4.08	3.78	4.36	−1.4	B5V
ρ	And	5.08	4.58	5.23	4.81	4.84	4.75	5.78	5.18	0.7	F5III
σ	And	4.08	3.91	4.23	4.81	4.84	4.75	4.11	4.52	1.1	A2V
τ	And	4.08	3.91	3.90	4.48	4.84	4.75	4.78	4.94	−1.5	B8III
υ	And	4.08	3.58	3.57	3.81	—	—	4.11	4.09	3.1	F8V
ϕ	And	5.08	4.91	4.90	5.14	4.84	—	4.11	4.25	−1.6	B7III
χ	And	5.08	5.24	5.23	—	4.84	—	5.11	4.98	0.0	G8III
ψ	And	—	—	—	5.14	4.84	5.08	5.78	4.95	−3.9	G5Ib+A0V
ω	And	—	—	—	—	5.84	—	4.78	4.83	2.1	F5IV
4	Aql	—	—	—	—	—	—	4.78	5.02	0.2	B9V
5	Aql	—	—	—	—	—	—	5.78	5.90	—	A2m
11	Aql	—	—	—	—	—	—	4.78	5.23	4.0	F8V
12i	Aql	—	—	—	—	—	3.75	4.45	4.02	—	K1IIIvar
14g	Aql	—	—	—	—	5.84	5.75	5.78	5.42	1.2	A1V
15h	Aql	—	—	—	—	5.84	5.75	5.78	5.42	0.1	K1III
18	Aql	—	—	—	—	—	—	4.78	5.09	−1.5	B8III
19	Aql	—	—	—	—	—	—	5.11	5.22	1.2	F0III-IV
20	Aql	—	—	—	—	—	—	5.78	5.34	−1.7	B3V
21	Aql	—	—	—	—	—	—	5.45	5.15	−2.3	B8II-III
22	Aql	—	—	—	—	—	—	5.78	5.59	0.6	A3IV
23	Aql	—	—	—	—	—	—	5.78	5.10	—	K2II-IIIvar
24	Aql	—	—	—	—	—	—	5.78	6.41	−0.5	K0IIIa:
26f	Aql	—	—	—	—	5.84	5.75	4.78	5.01	1.5	G8III-IV

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
27d	Aql	—	—	—	—	5.84	5.75	5.78	5.46	−1.1	B9III
28A	Aql	—	—	—	—	5.84	5.75	5.78	5.53	0.6	F0III
31b	Aql	—	—	—	—	5.84	5.75	5.11	5.16	4.0	G8IVvar
35c	Aql	—	—	—	—	5.84	5.75	5.45	5.80	0.6	A0V
36e	Aql	—	—	—	—	5.84	5.75	5.11	5.03	−0.8	M1III
37	Aql	—	—	—	—	—	—	5.45	5.12	0.3	G8III
42	Aql	—	—	—	—	—	—	5.78	5.67	1.9	F3IV
45	Aql	—	—	—	—	—	—	5.78	5.67	0.9	A3IV
51	Aql	—	—	—	—	—	—	5.78	5.39	2.6	F0V
57	Aql	—	—	—	—	—	—	4.78	5.71	−0.9	B7Vn
58	Aql	—	—	—	—	—	—	5.78	5.61	−0.6	A0III
62	Aql	—	—	—	—	—	—	5.78	5.68	−0.2	K4III
66	Aql	—	—	—	—	—	—	5.78	5.47	−0.4	K5III
68	Aql	—	—	—	—	—	—	5.78	6.13	0.2	B9V
69	Aql	—	—	—	—	—	—	4.78	4.91	0.1	K2III
70	Aql	—	—	—	—	—	—	4.78	4.89	−2.5	K5II
71	Aql	—	—	—	—	—	—	4.11	4.32	0.0	G8III
β	Aql	3.08	3.24	3.23	2.81	2.84	3.08	3.78	3.71	2.8	G8IVvar
γ	Aql	3.08	2.91	2.90	2.81	2.84	2.75	2.78	2.72	−2.2	K3II
δ	Aql	3.75	3.24	3.23	—	2.84	2.75	3.11	3.40	2.5	F0IV
ε	Aql	—	—	—	2.81	2.84	3.08	3.78	4.02	−0.2	K2III
ζ	Aql	3.08	2.91	2.90	2.81	2.84	2.75	2.78	2.99	0.3	A0Vn
η	Aql	3.08	3.24	3.23	—	2.84	3.08	—	3.78	−4.7	F6Ib
θ	Aql	3.08	2.91	2.90	5.81	2.84	2.75	2.78	3.23	−1.0	B9.5III
ι	Aql	3.08	4.24	4.23	—	2.84	3.08	4.11	4.36	−2.2	B5III
κ	Aql	5.08	4.91	4.90	—	2.84	3.08	4.78	4.95	−4.7	B0.5III
λ	Aql	3.08	3.24	3.23	—	2.84	2.75	3.11	3.44	0.2	B9Vn
μ	Aql	5.08	5.91	5.90	4.14	3.84	3.75	4.45	4.45	−0.1	K3III
ν	Aql	—	—	—	—	3.84	4.75	4.78	4.66	−4.6	F2Ib
ξ	Aql	—	—	4.90	—	4.84	4.75	4.78	4.71	0.2	K0III
o	Aql	3.41	4.91	—	5.81	4.84	5.42	5.45	5.10	3.4	F8V
π	Aql	—	—	—	5.14	4.84	4.75	5.78	5.72	—	G2III:+A1V
σ	Aql	4.75	5.91	5.90	4.48	4.84	4.75	4.78	5.17	−2.5	B3V+B3V
τ	Aql	4.08	5.91	5.90	—	5.84	5.75	5.45	5.52	0.2	K0III
υ	Aql	—	—	—	—	5.84	5.75	5.78	5.91	0.9	A3IV
ϕ	Aql	5.08	5.91	5.90	—	5.84	5.75	5.11	5.28	0.0	A1IV

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
χ	Aql	—	—	—	—	5.84	5.75	5.78	5.27	—	gG+B
ψ	Aql	—	—	—	—	5.84	5.75	5.78	6.24	−0.8	B9III-IV
ω	Aql	—	—	—	—	—	—	5.45	5.28	1.7	F0IV
1	Aqr	—	—	—	—	—	—	4.78	5.16	0.1	K1III
3	Aqr	—	—	—	—	—	—	4.11	4.42	—	M3IIIvar
5	Aqr	—	—	—	—	—	—	4.78	5.55	−0.8	B9III
7	Aqr	—	—	5.90	—	—	—	4.78	5.51	−0.4	K5III
11	Aqr	—	—	—	—	—	—	5.78	6.21	4.5	G1V
12	Aqr	—	—	—	—	—	—	5.11	5.9	0.4	G4III
14	Aqr	—	—	—	—	—	—	5.78	6.7	—	M0
15	Aqr	—	—	—	—	—	—	5.78	5.82	−1.1	B5V
16	Aqr	—	—	—	—	—	—	5.78	5.87	0.3	G7III
17	Aqr	—	—	—	—	—	—	5.78	5.99	−0.7	M0III
18	Aqr	—	—	—	—	—	—	5.78	5.49	2.8	FIV
19	Aqr	—	—	—	—	—	—	5.45	5.70	1.7	F0IV
21	Aqr	—	—	—	—	—	—	5.78	5.49	−0.2	K4III
25d	Aqr	5.08	6.24	6.23	5.48	5.84	5.75	5.45	5.10	0.2	K0III
26	Aqr	—	—	—	—	—	—	5.78	5.67	−0.2	K4III
28	Aqr	—	—	—	—	—	—	5.78	5.58	−0.2	K4III
30	Aqr	—	—	6.23	—	—	—	5.11	5.54	0.2	K0III
32	Aqr	—	—	—	—	—	—	5.78	5.30	—	A5m
35	Aqr	—	—	—	—	—	—	5.78	5.81	−2.6	B2.5IV
38e	Aqr	6.08	5.91	—	2.81	5.84	2.75	5.11	5.46	−1.6	B7III
41	Aqr	—	—	—	—	—	—	5.78	5.32	0.1	K0III+F2V
42	Aqr	—	—	—	—	—	—	5.78	5.34	0.2	K0III
44	Aqr	—	—	—	—	—	—	5.45	5.75	0.4	G6III
47	Aqr	—	—	—	—	—	—	5.45	5.13	0.1	K2III
49	Aqr	—	—	—	—	—	—	5.78	5.53	0.3	G9III:
51	Aqr	—	—	—	—	—	—	5.78	5.78	0.6	A0V
53f	Aqr	5.08	5.91	5.90	5.81	5.84	—	5.78	5.7	—	—
60	Aqr	—	—	—	—	—	—	5.78	5.89	0.4	G6III
66g1	Aqr	5.08	5.24	5.23	5.48	5.84	5.75	5.11	4.69	−0.2	K4III
67	Aqr	—	—	—	—	—	—	5.78	6.41	0.6	A0Vn
68g2	Aqr	5.08	5.24	5.23	—	—	5.75	5.78	5.26	0.3	G7III
69	Aqr	—	—	—	—	—	—	5.78	5.66	0.3	A0V
74	Aqr	—	—	—	—	—	—	5.78	5.80	−1.1	B9III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
83h1	Aqr	4.08	4.24	4.23	5.81	5.84	5.75	5.45	5.43	2.7	F2V
86c1	Aqr	4.08	3.91	3.90	4.81	—	5.75	4.11	4.47	0.3	G9III
88c2	Aqr	4.08	3.91	3.90	4.81	—	—	3.78	3.66	−2.1	K2II
89c3	Aqr	4.08	3.91	3.90	4.81	—	—	4.78	4.69	0.0	G2III+A2V
94	Aqr	—	—	5.23	—	—	—	5.45	5.08	2.9	G5IV
96	Aqr	—	—	—	—	—	—	5.45	5.55	1.6	F3IV
97	Aqr	—	—	—	—	—	—	5.45	5.20	2.1	A5Vn
98b1	Aqr	4.08	3.91	3.90	4.81	—	4.75	4.45	3.97	0.2	K0III
99b2	Aqr	4.08	3.91	3.90	4.81	—	4.75	4.78	4.39	−0.4	K5III
101b4	Aqr	4.08	3.91	3.90	5.14	—	4.75	4.45	4.71	1.1	A1n
103A1	Aqr	—	—	—	—	—	4.75	—	5.34	−0.4	K5III
104A2	Aqr	—	—	—	4.81	—	4.75	—	4.82	−2.3	G0II
106i1	Aqr	—	—	4.90	5.81	—	—	4.78	5.25	0.2	B9Vn
107A4	Aqr	—	—	—	—	—	5.75	—	5.6	1.7	F0IV
108i2,A5	Aqr	—	—	4.90	6.14	—	5.75	4.78	5.18	0.1	B9pSiSrCr
α	Aqr	3.08	3.24	3.23	2.48	2.84	3.75	2.78	2.90	−4.0	G2Ib
β	Aqr	3.08	3.24	3.23	2.81	2.84	2.75	2.78	2.91	−4.1	G0Ib
γ	Aqr	3.08	3.24	3.23	2.81	2.84	5.08	3.45	3.84	0.3	A0V
δ	Aqr	3.08	2.91	2.90	—	2.84	2.75	2.78	3.27	1.7	A3V
ε	Aqr	3.08	3.58	3.57	3.81	3.84	4.42	3.45	3.77	1.2	A1V
ζ	Aqr	3.08	3.24	3.23	3.81	3.84	3.75	3.11	3.71	—	—
η	Aqr	3.08	3.24	3.23	3.81	3.84	3.75	3.45	4.02	0.0	B9IV-Vn
θ	Aqr	4.08	3.91	3.90	4.14	3.84	5.75	4.11	4.16	1.7	G8III-IV
ι	Aqr	4.08	3.91	4.23	—	3.84	3.75	3.78	4.28	−0.4	B9IV-V
κ	Aqr	4.08	3.91	—	4.14	3.84	4.75	4.78	5.03	0.1	K2III
λ	Aqr	4.08	4.24	3.90	3.81	3.84	3.75	3.78	3.74	—	M2IIIvar
μ	Aqr	4.08	5.24	5.23	4.81	3.84	4.08	4.45	4.70	—	A3m
ν	Aqr	3.08	5.91	—	4.81	4.84	4.75	4.11	4.51	0.3	G8III
ξ	Aqr	5.08	4.91	4.90	4.81	4.84	5.75	4.45	4.70	2.1	A7V
o	Aqr	5.08	4.91	4.90	4.81	4.84	4.75	4.45	4.70	−1.0	B7IVe
π	Aqr	3.08	3.58	3.57	4.48	4.84	4.75	4.45	4.66	−3.5	B1Ve
ρ	Aqr	5.08	5.24	5.23	5.81	4.84	3.75	5.11	5.36	−1.2	B8IIIp(MnHg)
σ	Aqr	4.08	4.24	4.23	4.81	4.84	4.75	4.45	4.82	−0.3	A0IVs
τ	Aqr	4.08	3.91	3.90	4.81	4.84	—	3.78	4.01	−0.7	M0III
υ	Aqr	—	—	—	5.14	4.84	4.75	—	5.20	2.0	F4IV
ϕ	Aqr	4.08	4.24	4.23	4.81	4.84	4.75	4.11	4.22	−1.1	M2III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
χ	Aqr	4.08	3.91	4.23	5.14	4.84	5.75	5.11	5.06	−1.1	M3III
ψ1	Aqr	4.08	3.91	3.90	4.81	—	4.75	4.45	4.21	0.2	K0III
ψ2	Aqr	—	—	3.90	4.81	—	4.75	4.45	4.40	−1.1	B5Vn
ψ3	Aqr	4.08	3.91	3.90	4.81	—	4.75	4.78	4.98	0.6	A0V
ω1	Aqr	5.08	4.91	4.90	4.81	—	—	4.45	5.00	1.4	F0IV
ω2	Aqr	5.08	4.91	4.90	4.81	—	—	4.11	4.49	0.1	B9.5V
α	Ara	3.75	3.58	3.57	—	3.84	—	—	3.00	−2.8	B2Vne
β	Ara	4.08	3.91	3.90	—	3.84	—	—	2.85	−2.9	K3Ib-II
γ	Ara	3.75	4.24	4.23	—	3.84	—	—	3.30	−5.7	B1Ib
δ	Ara	—	—	—	—	2.84	—	—	3.60	−0.2	B8V
ε1	Ara	5.08	5.24	5.23	—	—	—	—	4.06	−0.2	K4III
ζ	Ara	4.08	3.91	3.90	—	2.84	—	—	3.13	−0.4	K5III
η	Ara	—	—	—	—	3.84	—	—	3.76	−0.4	K5III
θ	Ara	4.08	3.91	3.90	—	—	—	—	3.66	−5.7	B2Ib
σ	Ara	5.08	5.91	5.90	—	—	—	—	4.60	0.6	A0V
1	Ari	—	—	—	—	—	—	5.78	5.86	0.0	K1III+A6V
4	Ari	—	—	—	—	—	—	5.78	5.84	0.1	B9.5V
10	Ari	—	—	—	—	—	—	5.78	5.63	2.4	F8IV
14	Ari	—	—	—	—	—	—	4.78	4.98	0.6	F2III
15	Ari	—	—	—	—	—	—	5.78	5.70	−1.1	M3III
19	Ari	—	—	—	—	—	—	5.78	5.71	−1.0	M0III
20	Ari	—	—	—	—	—	—	5.78	5.80	2.9	F6IV-V
21	Ari	—	—	—	—	—	—	5.78	5.60	3.7	F6V
26	Ari	—	—	—	—	—	—	5.78	6.15	2.5	A9V
30	Ari	—	—	—	—	—	—	5.78	6.00	—	—
31	Ari	—	—	—	—	—	—	5.78	5.68	3.8	F7V
33d	Ari	5.08	5.24	5.23	5.14	—	—	5.45	5.30	1.4	A3V
35	Ari	5.08	4.91	4.90	3.81	—	—	4.78	4.66	−2.0	B3V
38	Ari	—	—	—	—	—	—	4.78	5.18	1.0	A7III-IV
39	Ari	5.08	4.91	4.90	3.81	—	—	4.78	4.51	0.1	K1III
41c	Ari	4.08	3.91	3.90	3.14	—	—	3.78	3.64	−0.5	B8Vn
49	Ari	—	—	—	—	—	—	5.78	5.90	—	A3m
52	Ari	—	—	—	—	—	—	5.78	6.8	−0.6	B7V
55	Ari	—	—	—	—	—	—	5.78	5.73	1.2	B8III
56	Ari	—	—	—	—	—	—	5.78	5.79	0.1	B9pSi
59	Ari	—	—	—	—	—	—	5.78	5.90	3.2	G8IV

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
62	Ari	—	—	—	—	—	—	5.78	5.52	0.4	G5III
63	Ari	—	—	—	—	—	—	5.11	5.09	−0.1	K3III
64	Ari	—	—	—	—	—	—	5.78	5.50	−0.2	K4III
65	Ari	—	—	—	—	—	—	5.78	6.08	1.2	A1V
α	Ari	2.75	2.58	2.57	2.48	2.84	1.75	1.78	2.00	0.2	K2III
β	Ari	3.08	2.91	2.90	3.48	2.84	2.75	2.45	2.64	1.6	A5V
γ	Ari	3.41	3.24	2.90	3.48	2.84	3.75	3.45	3.92	—	—
δ	Ari	4.08	3.91	3.90	3.81	3.84	3.75	4.11	4.35	—	K2IIIvar
ε	Ari	5.08	4.91	4.90	4.81	4.84	4.75	4.11	4.63	1.4	A2Vs
ζ	Ari	4.08	3.91	3.90	4.81	4.84	4.75	4.11	4.89	1.2	A1V
η	Ari	5.08	5.24	5.23	5.48	5.84	5.75	5.11	5.20	3.4	F5V
θ	Ari	5.08	5.24	5.23	5.48	—	—	5.45	5.62	0.9	A1Vn
ι	Ari	5.08	4.91	4.90	4.48	5.84	5.75	5.78	5.10	—	K1p
κ	Ari	—	—	—	5.81	5.84	5.42	5.45	5.03	—	A2m
λ	Ari	—	—	—	—	5.84	4.75	4.78	4.79	2.3	F0V
μ	Ari	—	—	—	5.81	5.84	5.75	5.45	5.69	0.6	A0V
ν	Ari	6.08	5.91	5.90	5.48	5.84	5.75	5.45	5.30	2.4	A7V
ξ	Ari	—	—	—	—	5.84	5.75	5.11	5.46	−1.3	B7IV
o	Ari	—	—	—	5.81	5.84	5.75	5.78	5.77	0.2	B9Vn
π	Ari	—	—	—	5.81	5.84	5.75	5.45	5.21	−1.2	B6V
ρ	Ari	5.08	4.91	—	5.81	—	—	5.78	5.63	3.4	F6V
σ	Ari	5.08	4.91	4.90	5.81	5.84	5.75	5.78	5.48	−0.6	B7V
τ	Ari	4.08	3.91	—	5.81	5.84	—	4.78	5.27	−1.6	B5IV
2 g	Aur	—	—	—	—	—	5.08	4.78	4.78	−0.1	K3III
4	Aur	—	—	—	—	—	—	5.78	4.95	1.2	A1V
9	Aur	—	—	—	—	—	—	4.78	5.00	2.3	F0V
14	Aur	6.08	—	—	—	—	—	5.11	5.05	1.3	A9IV
16	Aur	—	—	—	—	—	—	4.78	4.54	−0.4	K3III
19	Aur	—	—	—	—	—	—	5.11	5.00	—	A5IIvar
26	Aur	—	—	—	—	—	—	5.78	5.40	−0.3	B9.5V+F9III
36	Aur	—	—	—	—	—	—	5.78	5.70	—	B9.5pSiFe
38	Aur	—	—	—	—	—	—	5.78	6.10	0.2	K0III
40	Aur	—	—	—	—	—	—	5.78	5.30	—	A4m
41	Aur	—	—	—	—	—	—	5.78	5.78	1.7	A3V
42	Aur	—	—	—	—	—	—	5.78	6.50	2.6	F0V
43	Aur	—	—	—	—	—	—	5.78	6.38	0.1	K2III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
45	Aur	—	—	—	—	—	—	5.78	5.40	0.4	F5III
48	Aur	—	—	—	—	—	—	5.45	5.55	—	F5.5Ibv
49	Aur	—	—	—	—	—	—	5.45	5.27	0.6	A0Vnn
53	Aur	—	—	—	—	—	—	5.78	5.79	—	B9npEu
54	Aur	—	—	—	—	—	—	5.78	6.03	−1.9	B7III
63	Aur	—	—	—	—	—	—	4.78	4.90	−1.2	K4II-III
64	Aur	—	—	—	—	—	—	5.78	5.87	2.1	A5Vn
65	Aur	—	—	—	—	—	—	5.78	5.13	0.3	G8III
66	Aur	—	—	—	—	—	—	5.78	5.19	0.2	K0III
β	Aur	2.08	1.91	1.90	2.14	1.84	1.75	1.78	1.85	1.1	A2V
δ	Aur	4.08	3.91	3.90	3.81	3.84	3.75	4.11	3.72	0.2	K0III
ζ	Aur	4.08	3.91	3.90	4.14	3.84	3.75	3.78	3.75	−2.8	K5II+B5V
η	Aur	3.75	3.91	3.90	4.14	3.84	3.75	3.45	3.20	−1.7	B3V
θ	Aur	3.75	2.91	2.90	3.48	3.84	3.75	2.78	2.62	0.4	A0pSi
ι	Aur	3.41	3.24	3.23	3.81	3.84	3.75	2.78	2.70	—	K3IIvar
κ	Aur	3.75	4.24	4.23	—	3.84	4.08	4.45	4.35	—	G8IIIvar
λ	Aur	—	—	—	—	4.84	4.75	—	4.70	3.8	G0V
μ	Aur	—	—	—	—	4.84	4.75	—	4.86	—	A4m
ν	Aur	4.08	4.91	4.90	—	4.84	4.75	3.78	3.97	0.2	K0III
ξ	Aur	4.08	4.91	4.90	5.81	5.84	5.75	4.78	4.99	1.4	A2V
o	Aur	—	—	—	—	5.84	5.75	5.45	5.47	—	A0pCr
π	Aur	—	—	—	—	5.84	5.75	4.78	4.26	—	M3IIvar
ρ	Aur	—	—	—	—	5.84	5.75	5.45	5.22	−1.4	B5V
σ	Aur	—	—	—	—	5.84	5.08	5.78	4.97	−0.2	K4III
τ	Aur	—	—	—	—	5.84	4.75	4.78	4.52	0.3	G8III
υ	Aur	—	—	—	—	5.84	5.75	4.78	4.74	−0.7	M0III
ϕ	Aur	5.08	—	5.90	—	5.84	5.08	5.11	5.08	−0.2	K4IIIp
χ	Aur	5.08	—	5.90	—	5.84	5.08	4.78	4.74	−6.6	B5Iab
ψ1	Aur	—	—	—	—	—	—	4.78	4.87	—	K5Iabvar
ψ2	Aur	—	—	—	—	—	—	4.78	4.79	−0.1	K3III
ψ3	Aur	—	—	—	—	—	—	5.78	5.20	−1.2	B8III
ψ4	Aur	—	—	—	—	—	—	4.78	5.01	−0.4	K5III
ψ5	Aur	—	—	—	—	—	—	5.78	5.27	4.4	G0V
ψ6	Aur	—	—	—	—	—	—	5.78	5.22	0.1	K1III
ψ7	Aur	—	—	—	—	—	—	4.78	5.02	−0.1	K3III
ψ8	Aur	—	—	—	—	—	—	5.78	6.48	−0.3	B9.5pSi

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
ψ9	Aur	—	—	—	—	—	—	5.78	5.87	−1.2	B8III
1	Boo	—	—	—	—	—	—	5.78	5.78	1.2	A1V
2	Boo	—	—	—	—	—	—	5.78	5.62	0.3	G9III
3	Boo	—	—	—	—	—	—	5.78	5.95	0.2	G5III:+A7V:
6e	Boo	—	—	—	—	5.84	6.75	4.78	4.91	−0.2	K4III
9	Boo	—	—	—	—	—	—	4.78	5.01	—	K3IIIvar
10	Boo	—	—	—	—	—	—	5.78	5.76	0.6	A0Vs
11	Boo	—	—	—	—	—	—	5.78	6.23	0.5	A7III
12d	Boo	—	—	—	—	5.84	4.75	4.78	4.80	2.9	F9IVw
13	Boo	—	—	—	—	—	—	5.78	5.25	−0.9	M1.5III
14	Boo	—	—	—	—	—	—	5.78	5.50	1.9	F6IV
15	Boo	—	—	—	—	—	—	5.78	5.29	0.1	K1III
18	Boo	—	—	—	—	—	—	5.78	5.40	2.1	F5IV
20	Boo	—	—	—	—	—	—	4.78	4.86	−0.1	K3III
22f	Boo	—	—	—	—	5.84	4.75	4.78	5.39	—	F0m
24g	Boo	—	—	—	—	5.84	6.08	5.78	5.59	3.0	G3IV
26	Boo	—	—	—	—	—	—	5.78	5.90	1.9	F2IV
31	Boo	—	—	—	—	—	—	4.45	4.87	—	G8IIIvar
32	Boo	—	—	—	—	—	—	5.78	5.56	0.3	G8III
33h1	Boo	—	—	—	—	—	5.75	5.78	5.39	0.9	A1V
34	Boo	—	—	—	—	—	—	5.78	4.81	−1.1	M3III
38h2	Boo	—	—	—	—	5.84	5.75	5.78	5.70	2.3	F7IVw
39	Boo	—	—	—	—	—	—	5.78	5.69	2.8	F6V+F5V
40	Boo	—	—	—	—	—	—	4.78	5.64	1.2	F1III-IV
44i	Boo	—	—	—	—	5.84	—	4.78	4.76	4.4	G0Vnvar
45c	Boo	5.08	4.91	4.90	—	5.84	4.75	4.45	4.93	3.9	F5V
46b	Boo	5.08	4.91	4.90	—	5.84	5.75	5.78	5.67	−0.2	K2III
47k	Boo	—	—	—	—	5.84	—	4.78	5.57	1.2	A1V
50	Boo	—	—	—	—	—	—	5.11	5.38	−0.1	B9Vn
β	Boo	3.75	3.58	3.57	3.14	2.84	2.75	2.78	3.50	0.3	G8III
γ	Boo	3.08	2.91	2.90	2.81	2.84	2.75	2.45	3.00	—	A7IIIvar
δ	Boo	3.75	3.58	3.57	3.14	2.84	2.75	2.78	3.47	0.0	G8III
ε	Boo	3.08	2.91	2.90	2.81	2.84	2.75	2.11	2.7	−0.9	K0II-III
ζ	Boo	3.08	3.58	3.57	2.81	2.84	2.75	3.11	4.5	—	A3IVn
η	Boo	3.08	2.91	2.90	2.81	2.84	2.75	2.78	2.68	2.7	G0IV
θ	Boo	5.08	4.58	4.57	4.14	3.84	3.75	3.45	4.10	3.2	F7V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
ι	Boo	5.08	4.58	4.57	4.14	3.84	3.75	4.11	4.80	3.0	A9V
κ	Boo	5.08	4.58	4.57	4.14	3.84	3.75	4.11	4.54	1.2	A8IV
λ	Boo	5.08	4.91	4.90	3.81	3.84	3.75	3.78	4.18	—	A0sh
ξ	Boo	—	—	—	4.14	3.84	3.75	3.78	4.55	5.4	G8V
o	Boo	—	—	—	3.81	3.84	4.08	4.45	4.60	2.8	K0III
π	Boo	—	—	—	3.81	3.84	3.42	3.78	4.52	—	—
ρ	Boo	3.75	3.91	3.90	3.48	3.84	3.75	3.45	3.58	−0.1	K3III
σ	Boo	4.08	3.91	3.90	3.81	3.84	4.75	4.45	4.46	3.5	F3Vvw
τ	Boo	4.08	3.91	3.90	4.14	3.84	3.75	4.45	4.50	3.2	F6IV
υ	Boo	4.08	3.91	3.90	3.48	3.84	3.75	4.11	4.07	—	K5IIIvar
ϕ	Boo	—	—	—	—	4.84	5.75	4.78	5.24	1.7	G8III-IV
χ	Boo	—	—	—	—	4.84	4.75	4.78	5.26	1.4	A2V
ψ	Boo	5.08	4.91	4.90	—	4.84	4.75	4.11	4.54	0.1	K2III
ω	Boo	5.08	4.91	4.90	—	4.84	4.75	4.45	4.81	−0.2	K4III
1	Cam	—	—	—	—	—	—	5.78	5.77	−5.3	B0III
2	Cam	—	—	—	—	—	—	5.78	5.37	2.4	A8V
3	Cam	—	—	—	—	—	—	5.78	5.05	−0.1	K0III
4	Cam	—	—	—	—	—	—	5.78	5.34	—	A3m
5	Cam	—	—	—	—	—	—	5.78	5.52	0.4	B9.5V
7	Cam	—	—	—	—	—	—	4.78	4.47	0.9	A1V
9α	Cam	—	—	—	—	—	—	3.78	4.29	−6.5	O9.5Ia
10β	Cam	—	—	—	—	—	—	3.78	4.03	−4.1	G0Ib
11	Cam	—	—	—	—	—	—	4.78	5.03	−2.1	B2.5Ve
14	Cam	—	—	5.23	—	—	—	—	6.50	2.1	A7Vn
15	Cam	—	—	—	—	—	—	5.78	6.12	−1.1	B5V
16	Cam	—	—	—	—	—	—	5.45	5.23	0.3	A0Vn
17	Cam	—	—	—	—	—	—	5.78	5.42	−0.8	M1III
31	Cam	—	—	—	—	—	—	5.45	5.20	1.1	A2V
40	Cam	—	—	—	—	—	—	5.78	5.35	−0.1	K3III
42	Cam	—	—	—	—	—	—	4.78	5.13	−2.3	B4IV
43	Cam	—	—	—	—	—	—	4.78	5.11	−1.6	B7III
51	Cam	—	—	—	—	—	—	5.78	5.92	0.1	K2III
53	Cam	—	—	—	—	—	—	5.78	6.01	—	A2pSrCrEu
17	Cap	—	—	—	—	—	—	5.78	5.93	1.3	A0
24A	Cap	4.08	4.24	4.23	5.81	5.84	4.75	4.78	4.50	−0.8	M1III
29	Cap	—	—	—	—	—	—	5.78	5.28	−1.1	M3III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
30	Cap	—	—	—	—	—	—	5.78	5.41	−1.2	B8III
33	Cap	—	—	—	—	—	—	5.11	5.41	0.2	K0III
36b	Cap	5.08	4.58	4.57	5.81	5.84	5.75	4.45	4.51	0.4	G5III
37	Cap	—	—	—	—	—	—	5.78	5.69	2.8	F1V
41	Cap	—	—	—	—	—	—	5.11	5.24	0.3	G9III
42d1	Cap	4.08	5.24	5.23	—	—	5.75	4.78	5.18	2.7	G2IV
45	Cap	—	—	—	—	—	—	5.78	5.99	2.3	F0V
46c1	Cap	5.08	4.91	4.90	5.48	5.84	5.75	4.45	5.09	−1.1	G8II-III
47	Cap	—	—	—	—	—	—	5.78	6.00	−1.1	M3III
α1	Cap	—	—	—	—	—	3.75	3.11	4.24	−4.3	G3Ib
α2	Cap	—	—	—	—	—	2.75	3.11	3.57	0.3	G9III
β	Cap	3.08	3.24	3.23	2.81	2.84	2.75	2.78	3.01	—	—
γ	Cap	3.08	3.24	3.23	3.14	2.84	3.75	3.45	3.68	—	F0p
δ	Cap	3.08	2.91	3.90	3.14	2.84	2.75	2.78	2.87	1.9	Amv
ε	Cap	4.08	3.91	3.90	4.14	3.84	3.75	4.45	4.68	−2.1	B2.5Vp
ζ	Cap	4.08	4.24	4.23	4.81	4.84	4.75	3.78	3.74	—	G9p
η	Cap	5.08	5.24	5.23	4.81	4.84	4.75	5.11	4.84	3.1	A5V
θ	Cap	4.08	3.91	3.90	4.48	4.84	4.75	3.78	4.10	0.9	A1V
ι	Cap	4.08	3.91	3.90	4.48	4.84	4.75	4.11	4.28	0.3	G8III
κ	Cap	4.08	4.24	4.23	5.14	4.84	4.75	4.78	4.73	0.3	G8III
λ	Cap	5.08	4.91	4.90	5.14	4.84	4.75	5.11	5.58	1.2	A1V
μ	Cap	5.08	4.91	4.90	4.81	4.84	4.75	4.78	5.08	3.1	F1III
ν	Cap	6.08	5.24	5.23	5.81	5.84	5.75	4.78	4.76	0.4	B9.5V
ξ	Cap	6.08	6.24	—	6.14	5.84	5.75	5.78	5.85	3.8	F7V
o	Cap	6.08	5.91	5.90	—	5.84	—	5.11	5.52	—	—
π	Cap	6.08	5.91	5.90	—	5.84	—	4.78	5.25	−2.3	B8II-III
ρ	Cap	6.08	5.91	5.90	5.81	5.84	5.75	4.78	4.78	2.9	F2IV
σ	Cap	5.08	5.91	5.90	—	5.84	—	5.45	5.28	−2.2	K3II
τ	Cap	6.08	5.91	—	5.81	5.84	5.75	4.78	5.22	−2.2	B6III
υ	Cap	5.08	5.91	5.90	5.81	5.84	5.75	5.45	5.10	−1.1	M2III
ϕ	Cap	5.08	5.91	5.90	6.14	5.84	5.75	5.11	5.24	0.3	G9III
χ	Cap	5.08	5.91	5.90	5.81	—	—	5.78	5.28	0.6	A0V
ψ	Cap	4.08	3.91	3.90	6.14	5.84	4.75	4.11	4.13	3.9	F4V
ω	Cap	4.08	3.91	3.90	6.14	5.84	5.75	4.11	4.11	−0.2	K4III
χ	Car	2.08	3.91	3.90	—	—	—	—	3.50	−2.3	B3IVp
1e	Cas	—	—	—	—	—	4.75	5.11	4.84	−4.2	B0.5IV

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
2	Cas	—	—	—	—	—	—	5.78	5.70	0.3	A5III
4	Cas	—	—	—	—	—	—	5.78	4.98	−0.8	M1III
6	Cas	—	—	—	—	—	—	5.78	5.43	—	A3Iacomp
9	Cas	—	—	—	—	—	—	5.78	5.88	−0.4	A1III
10	Cas	—	—	—	—	—	—	5.78	5.58	−0.8	B9III
12	Cas	—	—	—	—	—	—	5.78	5.38	−0.8	B9III
21	Cas	—	—	—	—	—	—	5.78	5.66	0.3	A2IV
23	Cas	—	—	—	—	—	—	5.78	5.41	−1.5	B8III
31	Cas	—	—	—	—	—	—	5.78	5.29	0.6	A0Vnn
32	Cas	—	—	—	—	—	—	5.78	5.57	−0.3	B9IV
38	Cas	—	—	—	—	—	—	5.78	5.81	3.4	F6V
40	Cas	—	—	—	—	—	—	5.78	5.28	—	G8II-IIIvar
42c	Cas	—	—	—	5.81	5.84	5.75	5.78	5.18	−0.1	B9V
43	Cas	—	—	—	—	—	—	5.78	5.59	—	A0pSiSr
44	Cas	—	—	—	—	—	—	5.78	5.76	−1.5	B8IIIn
47	Cas	—	—	—	—	—	—	5.11	5.27	2.6	F0Vn
49f	Cas	—	—	—	—	—	4.08	5.45	5.22	0.3	G8III
50	Cas	—	—	—	—	—	—	3.78	3.98	1.1	A2V
52	Cas	—	—	—	—	—	—	5.78	6.00	0.9	A1Vn
53	Cas	—	—	—	—	—	—	5.78	5.58	−5.6	B8Ib
55	Cas	—	—	—	—	—	—	5.78	6.05	−1.1	B9V+G0II-III
α	Cas	3.08	2.91	2.90	2.48	2.84	2.75	—	2.23	—	K0II-IIIvar
β	Cas	3.08	2.91	2.90	2.81	2.84	2.42	2.11	2.27	1.6	F2III-IV
γ	Cas	2.75	2.58	2.57	2.48	2.84	2.75	1.78	2.39	—	B0IV:evar
δ	Cas	3.08	2.91	2.90	2.81	2.84	2.75	2.78	2.68	1.8	A5V
ε	Cas	4.08	3.91	3.90	2.81	2.84	2.75	3.11	3.37	—	B2pvar
ζ	Cas	3.75	3.58	3.57	3.81	3.84	3.75	3.78	3.66	−3.0	B2IV
η	Cas	4.08	3.91	3.90	3.81	3.84	3.75	3.45	3.42	—	—
θ	Cas	4.08	4.24	4.23	3.81	3.84	3.75	4.11	4.33	—	A7Vvar
ι	Cas	4.08	4.24	4.23	3.81	3.84	—	—	4.53	—	A5pSr
κ	Cas	4.41	4.24	4.23	3.81	3.84	3.75	4.11	4.16	−6.9	B1Ia
λ	Cas	—	—	—	5.81	4.84	4.75	4.78	4.73	−0.2	B8Vn
μ	Cas	—	—	—	4.81	4.84	4.75	5.78	5.12	5.7	G5Vp
ν	Cas	—	—	—	5.81	5.84	4.75	4.78	4.90	−0.8	B9III
ξ	Cas	—	—	—	5.81	5.84	5.75	5.78	4.81	−2.4	B2.5V
o	Cas	—	—	—	5.81	5.84	5.75	4.78	4.50	−2.5	B5III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
π	Cas	—	—	—	5.81	5.84	5.75	5.78	5.00	1.8	A5V
ρ	Cas	6.08	5.91	5.90	5.81	5.84	5.75	4.78	4.54	−9.5	G20e
σ	Cas	6.08	5.91	5.90	—	5.84	5.75	4.78	4.89	−3.8	B1V
τ	Cas	—	—	—	5.81	5.84	5.75	4.78	4.87	0.1	K1III
υ1	Cas	—	—	—	—	5.84	6.75	5.45	4.83	0.1	K2III
υ2	Cas	—	—	—	5.81	—	5.75	5.45	4.63	1.7	G8III-IV
ϕ	Cas	5.08	4.91	4.90	5.81	5.84	—	4.78	4.98	−8.8	F0Ia
χ	Cas	—	—	—	5.81	5.84	5.75	5.45	4.71	0.2	K0III
ψ	Cas	—	—	—	5.81	5.84	5.08	4.78	4.74	0.2	K0III
ω	Cas	—	—	—	—	—	—	4.78	4.98	−1.5	B8III
1i	Cen	3.75	3.91	3.90	—	4.84	4.08	4.11	4.23	2.5	F3V
2g	Cen	4.75	4.91	4.90	—	4.84	4.08	4.78	4.19	−0.7	M5III
3k	Cen	4.75	4.91	4.90	—	2.84	4.08	4.11	4.32	—	—
4h	Cen	4.75	4.91	4.90	—	4.84	4.08	4.11	4.73	−2.3	B4IV
γ	Cen	3.08	2.91	2.90	—	2.84	—	—	2.20	0.0	A1IV
δ	Cen	3.08	2.91	2.90	—	0.84	—	—	2.60	−3.0	B2IVne
ε	Cen	2.08	2.91	2.90	—	1.84	—	—	2.30	−4.4	B1III
ζ	Cen	2.75	2.91	2.90	—	2.84	—	—	2.60	−2.9	B2.5IV
η	Cen	3.08	2.91	2.90	—	4.84	—	—	2.31	—	B1Vn+A
θ	Cen	3.08	2.91	2.90	—	2.84	2.08	2.78	2.06	0.9	K0IIIb
ι	Cen	3.08	2.91	2.90	—	—	—	2.78	2.70	1.0	A2V
κ	Cen	4.08	3.58	3.57	—	3.84	—	—	3.10	−3.3	B2IV
μ	Cen	3.75	3.58	3.57	—	—	—	—	2.90	−3.0	B2IV-Ve
ν	Cen	3.75	3.58	3.57	—	3.84	—	—	3.40	−3.3	B2IV
π	Cen	—	—	—	—	3.84	—	—	3.90	−1.1	B5Vn
ρ	Cen	4.08	2.91	4.90	—	3.84	—	—	4.00	−1.7	B3V
σ	Cen	5.08	4.58	4.57	—	4.84	—	—	3.91	−1.7	B3V
τ	Cen	4.08	4.91	4.90	—	3.84	—	—	3.90	1.4	A2V
υ1	Cen	5.08	4.91	4.90	—	—	—	—	3.90	−2.7	B2IV-V
υ2	Cen	5.08	4.91	4.90	—	—	—	—	4.30	−2.3	F6II
ϕ	Cen	3.75	3.91	3.90	—	3.84	—	—	3.80	−3	B2IV
χ	Cen	3.75	3.58	3.57	—	4.84	—	—	4.40	−2.5	B2V
ψ	Cen	4.08	4.24	4.23	—	4.84	—	—	4.00	0.0	A0IV
4	Cep	—	—	—	—	—	—	5.45	5.60	2.4	A8V
6	Cep	—	—	—	—	—	—	5.78	5.18	−2.6	B3IVe
7	Cep	—	—	—	—	—	—	5.78	5.43	−0.6	B7V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
9	Cep	—	—	—	—	—	—	5.11	4.73	−5.7	B2Ib
11	Cep	—	—	—	—	—	—	4.78	4.56	0.2	K0III
15	Cep	—	—	—	—	—	—	5.78	6.70	−3.5	B1V
20	Cep	—	—	—	—	—	—	5.78	5.27	−0.2	K4III
24	Cep	—	—	—	—	—	—	4.45	4.77	0.3	G8III
25	Cep	—	—	—	—	—	—	5.78	5.75	−0.1	K3III
26	Cep	—	—	—	—	—	—	5.45	5.52	−5.7	B0.5Ib
30	Cep	—	—	—	—	—	—	5.11	5.20	0.6	A3IV
31	Cep	—	—	—	—	—	—	4.78	5.08	1.3	F3III-IV
α	Cep	3.08	2.91	2.90	2.81	2.84	2.75	2.45	2.44	1.4	A7IV-V
β	Cep	4.08	3.58	3.57	2.81	2.84	2.75	2.78	3.19	−3.9	B2III
γ	Cep	4.08	3.91	3.90	—	2.84	2.75	3.11	3.21	2.2	K1IV
ε	Cep	5.08	4.91	4.90	—	3.84	3.75	4.45	4.19	1.4	F0IV
ζ	Cep	4.08	5.91	3.90	3.81	3.84	4.08	3.45	3.35	−3.9	K1Ib
η	Cep	4.08	3.91	3.90	—	3.84	3.75	3.45	3.41	2.7	K0IV
θ	Cep	4.08	3.91	3.90	—	3.84	4.75	3.78	4.22	0.2	A7III
ι	Cep	3.75	3.58	3.57	3.48	3.84	3.75	3.45	3.52	0.2	K0III
κ	Cep	4.08	4.58	4.57	—	3.84	4.75	4.11	4.40	−0.8	B9III
λ	Cep	5.08	5.91	5.90	—	4.84	5.75	5.45	5.06	−6.3	O6If
ν	Cep	—	—	—	—	—	6.42	4.78	4.30	—	A2Iavar
ξ	Cep	5.08	4.91	4.90	—	4.84	4.75	4.45	4.12	—	—
o	Cep	—	—	—	—	4.84	4.75	5.45	4.75	0.2	K0III
π	Cep	—	—	—	—	4.84	4.75	4.78	4.41	—	G2III+(F0V)
ρ	Cep	—	—	—	—	—	5.75	5.45	5.52	1.4	A3V
2g	Cet	3.75	3.58	3.57	—	—	4.08	4.11	4.60	0.4	B9.5Vn
3	Cet	—	—	—	—	—	—	5.78	4.94	—	K3Ibvar
6f	Cet	3.75	3.58	3.57	—	—	4.75	4.45	4.89	3.8	F7V
7h	Cet	3.75	3.58	3.57	—	—	4.75	4.45	4.44	−1.1	M3III
9	Cet	—	—	—	—	—	—	5.78	6.38	4.6	G2V
13	Cet	—	—	—	—	—	—	5.45	5.20	4.0	F8V
18	Cet	—	—	—	—	—	—	5.78	6.15	4.4	G0V
20	Cet	—	—	—	—	—	—	5.11	4.77	−0.7	M0III
25	Cet	—	—	—	—	—	—	4.45	5.43	1.7	K0III-IV
28	Cet	—	—	—	—	—	—	5.78	5.58	0.9	A1V
37	Cet	—	—	—	—	—	—	5.78	5.13	3.5	F5V
38	Cet	—	—	—	—	—	—	5.78	5.70	3.4	F5V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
39	Cet	—	—	—	—	—	—	5.78	5.41	0.4	G5IIIe
42	Cet	—	—	—	—	—	—	5.78	5.87	1.2	G5III-IV+A5V
46	Cet	—	—	—	—	—	—	5.11	4.85	−0.1	K3III
47	Cet	—	—	—	—	—	—	5.78	5.66	2.7	?
48	Cet	—	—	—	—	—	—	5.11	5.12	1.2	A1V
49	Cet	—	—	—	—	—	—	5.78	5.62	1.7	A3V
50	Cet	—	—	—	—	—	—	5.78	5.42	0.1	K2III
56	Cet	—	—	—	—	—	—	5.45	4.85	−0.2	K4III
60	Cet	—	—	—	—	—	—	5.78	5.43	0.3	A5III
63	Cet	—	—	—	—	—	—	5.78	5.93	0.3	G9III
64	Cet	—	—	—	—	—	—	5.78	5.60	2.8	G0IV
67	Cet	—	—	—	—	—	—	5.78	5.51	0.3	G8III-IV
69	Cet	—	—	—	—	—	—	5.78	5.28	−1.1	M2III
70	Cet	—	—	—	—	—	—	5.78	5.42	2.3	F0Vn
75	Cet	—	—	—	—	—	—	5.45	5.35	0.4	G3III:
80	Cet	—	—	—	—	—	—	5.78	5.53	−0.7	M0III
81	Cet	—	—	—	—	—	—	5.78	5.65	0.4	G5III:+A7V:
94	Cet	—	—	—	—	—	—	5.11	5.06	3.5	F8V
95	Cet	—	—	—	—	—	—	5.78	5.37	—	K1IV
97	Cet	—	—	—	—	—	—	5.78	5.67	0.3	G8.5III
α	Cet	3.08	2.91	2.90	1.81	1.84	1.75	2.11	2.53	−1.1	M2III
β	Cet	3.08	2.58	2.57	1.81	1.84	2.75	1.78	2.04	0.7	G9.5III
γ	Cet	3.08	2.91	2.90	2.81	2.84	2.75	3.11	3.47	1.9	A3V
δ	Cet	3.08	3.24	3.23	2.81	2.84	2.75	3.78	4.07	−3.3	B2IV
ε	Cet	4.08	3.91	3.90	3.14	2.84	2.75	4.45	4.82	3.7	F5IV-V
ζ	Cet	3.08	3.24	3.23	2.48	2.84	—	2.78	3.73	−0.2	K2III
η	Cet	3.08	3.24	3.23	3.14	2.84	2.75	2.78	3.45	0.1	K2III
θ	Cet	3.08	3.24	3.23	2.81	2.84	2.75	2.78	3.60	0.2	K0III
ι	Cet	3.41	3.24	3.23	2.81	2.84	2.75	3.11	3.54	0.1	K2III
κ	Cet	—	—	—	—	—	—	4.78	4.83	4.9	G5Vvar
λ	Cet	4.08	3.91	3.90	3.81	3.84	3.75	4.45	4.66	−1.9	B6III
μ	Cet	3.75	3.91	3.90	3.81	3.84	3.75	3.78	4.20	0.9	F1III-IV
ν	Cet	4.08	3.91	3.90	4.14	3.84	4.08	4.78	4.86	0.0	G8III
ξ1	Cet	4.08	3.91	4.23	4.14	—	5.75	4.11	4.34	−2.2	G8II
ξ2	Cet	4.08	3.91	—	4.14	—	4.42	3.78	4.28	—	B9III
π	Cet	3.08	3.58	3.57	3.81	3.84	3.42	3.78	4.25	−0.9	B7V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
ρ	Cet	4.08	3.91	3.90	3.81	3.84	3.75	4.78	4.89	0.4	B9.5Vn
σ	Cet	4.08	3.91	3.90	3.81	3.84	3.75	4.78	4.75	2.0	F4IV
τ	Cet	3.08	3.24	3.23	—	3.84	3.08	3.11	3.50	5.7	G8Vp
υ	Cet	4.08	3.91	3.90	—	—	—	3.78	4.00	−0.7	M0III
ϕ1	Cet	4.75	5.24	5.23	—	—	4.75	5.78	4.76	0.2	K0III
ϕ2	Cet	5.08	5.91	5.90	—	—	4.75	5.78	5.19	4.0	F7IV-V
ϕ3	Cet	—	—	—	—	—	4.75	5.78	5.31	−0.2	K4III
ϕ4	Cet	—	—	—	—	—	4.75	5.78	5.61	0.3	G7III
χ	Cet	—	—	—	4.48	4.84	4.75	4.45	4.65	2.7	F3III
10	CMa	—	—	—	—	—	—	4.78	5.20	−2.5	B2V
11	CMa	—	—	—	—	—	—	4.78	5.28	−0.8	B9III
15	CMa	—	—	—	—	—	—	5.45	4.80	−3.9	B1IV
27	CMa	—	—	—	—	—	—	5.45	4.65	−3.2	B3III
29	CMa	—	—	—	—	—	—	4.78	4.98	—	O7e
β	CMa	3.08	2.91	2.90	2.14	1.84	1.75	2.45	1.98	−5.0	B1II-III
γ	CMa	4.08	5.91	3.90	3.14	2.84	2.75	4.11	4.10	−3.4	B8II
δ	CMa	3.41	2.91	2.90	2.81	2.84	2.08	1.78	1.80	−8.3	F8Ia
ε	CMa	3.08	2.91	2.90	2.81	2.84	2.42	1.45	1.50	−4.4	B2II
ζ	CMa	3.08	2.91	2.90	2.81	2.84	2.75	2.45	3.00	−2.4	B2.5V
η	CMa	3.41	3.24	3.23	2.81	2.84	2.42	2.45	2.40	−7.0	B5Ia
θ	CMa	4.08	3.91	4.23	3.81	3.84	4.75	4.11	4.05	−0.2	K4III
ι	CMa	4.08	3.91	3.90	3.81	3.84	3.75	4.45	4.40	−3.9	B3II
κ	CMa	4.08	3.91	3.90	—	3.84	—	3.78	3.96	−3.4	B1.5IVne
λ	CMa	4.08	4.91	4.90	—	3.84	3.75	4.11	4.50	−1.4	B4V
μ	CMa	5.08	4.91	4.90	4.81	4.84	3.75	4.78	5.00	—	G5III+A2
ν1	CMa	—	—	—	—	—	4.75	—	5.70	2.2	F3IV-Vcomp
ν2	CMa	5.08	4.91	4.90	4.81	—	4.75	4.78	3.96	2.5	K1III
ν3	CMa	5.08	4.91	4.90	—	—	4.75	5.78	4.43	0.1	K1III
ξ1	CMa	5.08	4.91	4.90	—	—	4.75	4.78	4.33	−4.5	B0.5IV
ξ2	CMa	5.08	4.91	4.90	—	—	4.75	4.78	4.50	0.6	A0V
o1	CMa	5.08	4.91	4.90	4.48	—	—	4.78	3.87	−5.8	K3Iab
o2	CMa	4.08	3.91	3.90	4.48	—	—	3.11	3.00	−7.1	B3Ia
π	CMa	5.08	4.91	—	—	—	—	5.78	4.69	0.6	F2III
σ	CMa	—	—	—	—	—	—	4.78	3.47	−0.2	K4III
τ	CMa	—	—	—	—	—	—	4.78	4.40	−6.4	O9Ib
ω	CMa	—	—	—	—	—	—	4.78	3.73	−2.7	B2IV-Ve

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
1	CMi	—	—	—	—	—	—	5.78	5.30	1.2	A5IV
6	CMi	—	—	—	—	—	—	4.78	4.54	0.1	K2III
11	CMi	—	—	—	—	—	—	5.11	5.30	0.9	A1Vnn
14	CMi	—	—	—	—	—	—	5.78	5.29	0.2	K0III
β	CMi	4.08	3.91	3.90	2.48	2.84	2.75	2.78	2.90	—	B8Vvar
γ	CMi	—	—	—	—	4.84	5.75	4.78	4.32	−0.4	K3III
δ1	CMi	—	—	—	—	4.84	5.75	5.78	5.20	0.6	F0III
δ2	CMi	—	—	—	—	—	5.75	5.78	5.60	3.0	F2V
δ3	CMi	—	—	—	—	—	5.75	—	5.81	0.6	A0Vnn
ε	CMi	—	—	—	—	5.84	5.75	5.11	4.99	0.3	G8III
ζ	CMi	—	—	—	—	5.84	4.75	5.78	5.13	−3.4	B8II
η	CMi	—	—	—	—	5.84	5.75	5.78	5.25	0.6	F0III
8	Cnc	—	—	—	4.81	—	—	5.78	5.12	0.9	A1V
12	Cnc	—	—	—	—	5.84	—	—	6.20	3.1	F3V
27	Cnc	—	—	—	—	—	—	5.78	5.50	−1.1	M3III
29	Cnc	—	—	—	—	—	—	5.78	5.90	1.8	A5V
36c	Cnc	—	—	—	—	5.84	6.75	5.78	5.88	1.7	A3V
45A1	Cnc	—	—	—	—	—	5.75	5.78	5.62	0.3	A3V+G0III
49b	Cnc	—	—	—	—	5.84	5.75	5.78	5.66	—	A1pEuCr
50A2	Cnc	—	—	—	—	—	5.75	5.78	5.87	1.2	A1V
57	Cnc	—	—	—	—	—	—	5.78	5.39	0.3	G7III
63	Cnc	—	—	—	—	—	—	5.78	5.60	1.7	F0IV
67	Cnc	—	—	—	—	—	—	5.78	6.00	2.4	A8Vn
75	Cnc	—	—	—	—	—	—	5.78	5.98	4.1	G5IV-V
83	Cnc	—	—	—	—	—	—	5.78	6.60	—	F5
α	Cnc	4.08	3.91	3.90	—	—	—	3.78	4.20	—	A5m
β	Cnc	3.75	3.91	3.23	—	2.84	3.42	3.45	3.52	−0.2	K4III
γ	Cnc	3.75	3.91	3.90	3.81	3.84	3.75	4.11	4.66	0.0	A1IV
δ	Cnc	3.75	3.91	3.90	3.81	3.84	3.75	3.78	3.94	0.2	K0II
ε	Cnc	—	—	—	—	3.84	6.75	—	6.30	—	Am
ζ	Cnc	4.08	4.24	4.23	3.81	3.84	5.08	4.45	5.00	—	—
η	Cnc	4.41	4.24	4.23	4.81	4.84	6.08	5.78	5.33	−0.1	K3III
θ	Cnc	4.41	4.24	4.23	4.81	4.84	5.42	5.78	5.35	−0.4	K5III
ι	Cnc	4.08	3.91	3.90	4.81	—	4.75	3.78	3.92	—	—
κ	Cnc	4.41	4.24	4.23	4.48	4.84	4.08	4.78	5.25	−1.5	B8IIIpMn
λ	Cnc	—	—	—	—	4.84	5.75	5.78	5.98	0.1	B9.5V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
μ	Cnc	5.08	4.58	5.23	4.81	—	—	5.45	5.30	3.0	G2IV
ν	Cnc	5.08	4.91	4.90	5.81	5.84	5.75	5.78	5.48	−0.9	A0III
ξ	Cnc	5.08	4.91	4.90	5.81	5.84	5.08	4.78	5.14	−0.1	K0III
o	Cnc	—	—	—	5.81	—	—	5.78	5.20	0.0	A5III
π	Cnc	4.41	4.24	—	—	—	6.75	5.78	5.34	0.1	K1III
ρ1	Cnc	—	—	—	—	—	5.75	5.78	5.95	5.3	G8V
ρ2	Cnc	—	—	—	—	—	5.75	5.78	5.22	−0.8	G8II-III
σ1	Cnc	—	—	—	—	—	5.75	5.78	5.66	2.1	A8Vms
σ2	Cnc	—	—	—	—	—	5.08	5.78	5.40	1.5	A7IV
σ3	Cnc	—	—	—	—	—	5.75	4.78	5.20	0.3	G9III
σ4	Cnc	—	—	—	—	—	7.08	—	5.82	1.4	A2V
τ	Cnc	—	—	—	—	5.84	6.08	5.78	5.43	0.3	G8III
υ1	Cnc	—	—	—	—	—	5.75	5.78	5.75	0.6	F0IIIn
υ2	Cnc	—	—	—	—	—	6.08	5.78	6.36	0.3	G9III
ϕ1	Cnc	—	—	—	—	—	6.08	5.78	5.57	−0.4	K5III
ϕ2	Cnc	—	—	—	—	—	5.75	5.78	4.93	—	—
χ	Cnc	—	—	—	—	5.84	4.75	5.78	5.10	4.0	F6V
ψ	Cnc	—	—	—	—	5.84	—	5.78	4.93	—	—
ω	Cnc	—	—	—	—	5.84	—	5.78	5.83	0.3	G8III:
α	Col	2.08	2.91	2.90	—	—	—	1.78	2.60	−1.0	B7IV
β	Col	2.08	2.91	2.90	—	—	—	2.78	3.12	0.1	K1.5III
γ	Col	4.08	3.58	4.23	—	—	—	3.78	4.36	−2.6	B2.5IV
δ	Col	4.08	3.91	3.90	—	—	—	3.78	3.85	−2.2	G7II
ε	Col	4.08	3.91	4.23	—	—	—	3.78	3.87	−1.0	K1II/III
η	Col	3.75	3.91	3.90	—	—	—	—	3.96	0.2	K0III
θ	Col	4.08	3.91	3.90	—	—	—	—	5.00	−0.6	B8:IV
κ	Col	4.08	4.91	4.90	—	—	—	—	4.37	−1.9	G8II
λ	Col	4.08	3.58	4.23	—	—	—	—	4.90	−1.1	B5V
μ	Col	4.08	3.58	4.23	—	—	—	—	5.20	−3.7	B1IV/V
2	Com	—	—	—	—	—	—	5.78	5.87	1.9	F0IV-Vcomp
4	Com	—	—	—	—	—	—	5.78	5.66	−0.5	K4III
5	Com	—	—	—	—	—	—	5.78	5.57	−0.9	K0II-III
6	Com	—	—	—	—	—	—	4.78	5.10	1.4	A4V
7h	Com	—	4.91	—	—	—	4.08	5.11	4.95	0.2	K0III
11	Com	—	—	—	—	—	—	4.78	4.74	0.3	G8III
12e	Com	—	—	—	—	—	4.75	4.78	4.80	—	G5III+A5

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
13f	Com	—	—	—	—	—	4.08	4.78	5.18	1.7	A3V
14b	Com	—	—	—	—	—	4.08	4.45	5.00	—	F0p,shell
15c(γ)	Com	—	4.91	4.90	—	—	4.08	4.11	4.36	—	K2IIICN+1
16a	Com	—	—	—	—	—	4.08	4.78	5.00	1.9	A4V
17d	Com	—	—	—	—	—	4.08	4.78	5.29	—	A0p
18	Com	—	—	—	—	—	—	5.78	5.50	0.4	F5III
20	Com	—	—	—	—	—	—	5.78	5.69	1.4	A3V
21g	Com	—	—	—	—	—	4.75	5.45	5.46	—	A2pvar
23k	Com	—	4.91	—	—	—	3.75	4.78	4.81	−0.3	A0IV
24	Com	—	—	—	—	—	—	4.78	4.78	—	—
26	Com	—	—	—	—	—	—	5.78	5.68	−0.4	K5III
27	Com	—	—	—	—	—	—	4.78	5.12	−0.1	K3III
29	Com	—	—	—	—	—	—	5.78	5.70	1.2	A1V
30	Com	—	—	—	—	—	—	5.78	5.78	1.1	A2V
31	Com	—	—	—	—	—	—	4.78	4.94	0.6	G0III
35	Com	—	—	—	—	—	—	4.78	4.90	—	G8III+F6:
36	Com	—	—	—	—	—	—	4.78	4.78	−0.7	M0III
37	Com	—	—	—	—	—	—	4.78	4.90	0.1	K1IIIp
39	Com	—	—	—	—	—	—	5.78	5.99	3.3	F4V
40	Com	—	—	—	—	—	—	5.78	5.60	3.7	M5III
41	Com	—	—	—	—	—	—	4.78	4.80	−0.4	K5III
42(α)	Com	—	—	—	—	—	—	4.11	4.31	—	—
43(β)	Com	—	—	—	—	—	—	3.78	4.26	4.7	F9.5V
α	CrA	4.08	4.91	4.90	—	3.84	—	—	4.11	0.9	A0/A1V
β	CrA	4.08	4.91	4.90	—	4.84	—	—	4.11	−0.9	K0II/IIICNIb
γ	CrA	4.08	4.91	4.90	—	—	—	—	4.26	—	—
δ	CrA	5.08	5.24	5.23	—	—	—	—	4.59	0.1	K1III
ε	CrA	6.08	5.91	5.90	—	5.84	—	—	4.87	2.2	F3IV/V
ζ	CrA	4.08	4.91	4.90	—	—	—	—	2.60	0.6	A3IV
θ	CrA	5.08	4.91	4.90	—	4.84	—	—	4.64	0.4	G5III
κ	CrA	—	—	—	—	4.84	—	—	4.8	—	—
λ	CrA	5.08	5.24	5.23	—	4.84	—	—	5.13	0.9	A0/A1V
ν	CrA	—	—	5.90	—	—	—	—	5.24	0.4	G5/G6III
α	CrB	1.75	1.91	1.90	1.48	1.84	2.08	1.78	2.21	0.4	A0V
β	CrB	3.75	3.91	3.90	3.81	3.84	3.75	3.45	3.68	—	F0p
γ	CrB	4.08	3.91	3.90	3.81	3.84	3.75	3.45	3.84	0.9	A1Vs

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
δ	CrB	4.08	3.91	3.90	3.81	3.84	3.75	4.11	4.63	1.8	G5III-IV
ε	CrB	4.08	3.91	3.90	3.81	3.84	4.08	3.78	4.20	−0.1	K3III
ζ	CrB	—	—	—	—	3.84	3.75	3.78	4.64	—	—
η	CrB	3.75	4.58	4.57	—	4.84	4.75	4.78	5.07	—	—
θ	CrB	5.08	4.24	4.23	4.81	4.84	4.08	3.78	4.14	−0.9	B6Vnn
ι	CrB	4.08	3.91	3.90	6.14	4.84	5.08	4.45	4.99	0.4	A0pHg
κ	CrB	—	—	—	—	4.84	4.75	4.45	4.82	1.7	K0III-IV
λ	CrB	—	—	—	—	4.84	4.75	5.45	5.40	3.6	F0IV
μ	CrB	—	—	—	—	4.84	4.75	4.78	5.11	−0.9	M1.5III
$\nu1$	CrB	—	—	—	—	—	4.75	—	5.20	−1.1	M2II
$\nu2$	CrB	—	—	—	—	—	4.75	—	5.39	−0.4	K5III
ξ	CrB	—	—	—	—	4.84	4.75	4.78	4.85	0.2	K0III
o	CrB	5.08	4.91	4.90	—	5.84	5.75	5.78	5.51	0.2	K0III
π	CrB	6.08	5.91	5.90	5.81	5.84	4.75	5.78	5.56	0.3	G90III:
ρ	CrB	—	—	—	—	5.84	5.75	5.45	5.40	3.5	G2V
σ	CrB	—	—	—	—	5.84	5.75	5.78	5.29	—	—
τ	CrB	—	—	—	—	5.84	5.75	4.45	4.76	1.4	K0III-IV
υ	CrB	—	—	—	—	5.84	5.75	5.45	5.78	1.7	A3V
α	Crt	4.08	3.91	3.90	3.81	3.84	3.75	3.78	4.07	0.2	K0III
β	Crt	3.75	3.91	—	—	3.84	3.08	3.78	4.48	2.7	A2III
γ	Crt	4.08	3.91	3.90	3.81	3.84	3.75	3.78	4.08	2.1	A5V
δ	Crt	4.08	3.91	3.90	3.81	3.84	3.75	3.11	3.56	1.5	G8III-IV
ε	Crt	4.08	4.24	4.23	—	3.84	3.75	4.78	4.83	−0.4	K5III
ζ	Crt	3.75	5.24	5.23	—	3.84	3.75	4.78	4.73	0.3	G8III
η	Crt	4.41	4.24	4.23	—	3.84	3.75	5.78	5.17	0.6	A0V
θ	Crt	4.08	4.24	4.23	—	3.84	3.75	4.11	4.69	0.1	B9.5Vn
ι	Crt	—	—	—	—	4.84	—	5.45	5.48	3.8	F7V
κ	Crt	—	—	—	—	5.84	4.75	5.78	5.94	1.4	F4III-IV
λ	Crt	—	—	—	—	5.84	5.08	5.45	5.09	0.4	F5III
β	Cru	2.08	1.91	1.90	—	—	—	—	1.20	−5.0	B0.5III
γ	Cru	2.08	1.91	1.90	—	—	—	—	3.90	−1.1	B5V
δ	Cru	4.08	3.24	3.23	—	—	—	—	2.80	−3.0	B2IV
μ	Cru	4.08	4.24	4.23	—	—	—	—	3.70	—	—
α	Crv	3.08	3.24	3.23	—	2.84	3.75	3.78	4.00	3.0	F2III-IV
β	Crv	3.08	2.91	2.90	3.14	2.84	2.75	2.11	2.65	−1.9	G5II
γ	Crv	3.08	2.91	2.90	2.81	2.84	2.75	1.78	2.59	−1.5	B8III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
δ	Crv	3.08	2.91	2.90	2.81	2.84	2.75	2.11	2.95	0.2	B9V
ε	Crv	3.08	2.91	2.90	3.48	3.84	3.75	2.78	3.00	—	K2IIIvar
ζ	Crv	5.08	4.91	4.90	—	4.84	4.75	4.78	5.22	−0.5	B8Vn
η	Crv	4.08	3.91	3.90	—	4.84	4.75	4.78	4.31	2.5	F2III-IV
2	CVn	—	—	—	—	—	—	5.78	5.66	−0.8	M1III+F7V
3	CVn	—	—	—	—	—	—	5.78	5.29	−0.7	M0III
4	CVn	—	—	—	—	—	—	5.78	6.06	1.6	F3IV
5	CVn	—	—	—	—	—	—	5.78	4.80	0.0	G7III
6	CVn	—	—	—	—	—	—	4.78	5.02	1.7	G8III-IV
7	CVn	—	—	—	—	—	—	5.11	6.21	3.8	F7V
9	CVn	—	—	—	—	—	—	4.11	6.40	2.4	A7Vn
10	CVn	—	—	—	—	—	—	5.78	6.00	5.1	G0V
11	CVn	—	—	—	—	—	—	5.78	6.27	—	A6m
14	CVn	—	—	—	—	—	—	4.78	5.20	0.2	B9V
15	CVn	—	—	—	—	—	—	4.78	6.28	−1.6	B7III
17	CVn	—	—	—	—	—	—	4.78	5.91	0.8	A9III-IV
19	CVn	—	—	—	—	—	—	5.78	5.79	2.4	A7V
20	CVn	—	—	—	—	—	—	4.45	4.73	0.6	F3III
21	CVn	—	—	—	—	—	—	4.78	5.15	0.6	A0V
23	CVn	—	—	—	—	—	—	5.45	5.60	0.1	K1III
24	CVn	—	—	—	—	—	—	4.78	4.70	2.1	A5V
25	CVn	—	—	—	—	—	—	4.78	4.82	0.5	A7III
α	CVn	3.08	2.91	2.90	—	—	—	2.78	2.81	—	—
β	CVn	5.08	4.91	4.90	—	—	—	5.78	4.29	4.4	G0V
2	Cyg	—	—	—	—	—	—	4.78	4.98	−2.3	B3IV
4	Cyg	—	—	—	—	—	—	4.78	5.16	—	B9pSi
7	Cyg	—	—	—	—	—	—	5.78	5.75	0.9	A1V
8	Cyg	—	—	—	—	—	—	4.45	4.72	−2.3	B3IV
9	Cyg	—	—	—	—	—	—	5.78	5.38	—	gG+A
11	Cyg	—	—	—	—	—	—	5.78	6.04	−0.2	B8Vn
14	Cyg	—	—	—	—	—	—	5.45	5.40	−1.1	B9III
15	Cyg	—	—	—	—	—	—	5.11	4.89	0.3	G8III
16c1	Cyg	—	—	—	—	5.84	5.75	5.45	5.32	—	—
17	Cyg	—	—	—	—	—	—	5.11	4.99	3.3	F5III
19	Cyg	—	—	—	—	—	—	5.78	5.12	−1.1	M2III
20d	Cyg	—	—	—	—	5.84	—	5.11	5.03	—	K3IIIvar

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
22	Cyg	—	—	—	—	—	—	5.11	4.93	−1.6	B5IV
23	Cyg	—	—	—	—	—	—	5.11	5.14	−1.1	B5V
25	Cyg	—	—	—	—	—	—	5.45	5.17	−2.6	B3IV
26e,c2	Cyg	—	—	—	—	5.84	5.75	5.45	5.05	−1.0	K1II-III
27b1	Cyg	—	—	—	—	—	4.75	5.45	5.36	3.2	K0IV
28b2	Cyg	—	—	—	—	5.84	4.75	4.78	4.93	−2.1	B2.5V
29b3	Cyg	—	—	—	—	—	4.75	4.78	4.97	1.4	A2V
33	Cyg	—	—	—	—	—	—	4.11	4.30	1.0	A3IV-Vn
34p	Cyg	—	—	—	—	—	—	4.78	4.81	−1.7	B2pe
35m	Cyg	—	—	—	—	—	5.75	5.11	5.17	—	F5Ib+B8
36	Cyg	—	—	—	—	—	—	5.78	5.58	1.1	A2V
39h	Cyg	—	—	—	—	—	5.75	4.78	4.43	−0.1	K3III
40	Cyg	—	—	—	—	—	—	5.78	5.62	1.7	A3V
41i	Cyg	—	—	—	—	—	3.75	4.11	4.00	−2.0	F5II
42	Cyg	—	—	—	—	—	—	5.78	5.88	−5.1	A1Ib
47l	Cyg	—	—	—	—	—	5.75	5.11	4.61	−3.8	K2Ib+B3V
48	Cyg	—	—	—	—	—	—	5.78	6.32	−1.2	B8IIIn
49	Cyg	—	—	—	—	—	—	5.78	5.5	—	—
51	Cyg	—	—	—	—	—	—	5.45	5.38	−2.5	B2V
52k	Cyg	—	—	—	—	—	5.75	4.11	4.22	0.2	K0III
55	Cyg	—	—	—	—	—	—	5.45	4.84	−6.8	B3Ia
57	Cyg	—	—	—	—	—	—	5.11	4.80	−1.4	B5V
59f1	Cyg	—	—	—	—	—	5.08	5.11	4.74	—	B1ne
60	Cyg	—	—	—	—	—	—	5.78	5.37	−3.8	B1V
61	Cyg	—	—	—	—	—	—	5.11	4.79	—	—
63f2	Cyg	—	—	—	—	—	5.75	5.11	4.55	−2.3	K4II
68A	Cyg	—	—	—	—	4.84	5.75	4.78	5.00	—	O8
69	Cyg	—	—	—	—	—	—	5.78	5.94	−5.8	B0IV
70	Cyg	—	—	—	—	—	—	5.45	5.30	−2.0	B3V
71g	Cyg	—	—	—	—	5.84	5.75	4.78	5.24	0.2	K0III
72	Cyg	—	—	—	—	—	—	4.78	4.90	0.1	K1III
74	Cyg	—	—	—	—	—	—	4.78	5.00	2.1	A5V
75	Cyg	—	—	—	—	—	—	5.45	5.11	—	M1IIIvar
79	Cyg	—	—	—	—	—	—	5.11	5.65	0.6	A0V
α	Cyg	2.08	1.91	1.90	1.48	1.84	1.75	1.45	1.25	−7.5	A2Ia
β	Cyg	3.08	3.24	3.23	2.81	2.84	3.08	2.78	2.93	—	—

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
γ	Cyg	3.08	2.58	2.57	2.48	2.84	2.75	2.45	2.20	−4.3	F8Ib
δ	Cyg	3.08	2.91	2.90	2.81	2.84	3.08	2.78	2.87	−1.0	B9.5III
ε	Cyg	3.08	2.91	2.90	3.14	2.84	2.75	2.45	2.50	0.7	K0III
ζ	Cyg	3.08	2.91	2.90	3.14	2.84	2.75	2.78	3.20	−0.4	G8III-IIIa
η	Cyg	3.75	4.91	4.90	3.48	3.84	5.75	4.11	3.89	—	K0IIIvar
θ	Cyg	4.08	4.24	4.23	4.14	3.84	3.75	4.45	4.48	3.2	F4V
ι	Cyg	3.75	3.91	3.90	4.14	3.84	5.75	3.78	3.79	2.1	A5Vn
κ	Cyg	3.75	3.91	3.90	4.14	3.84	3.75	3.78	3.80	−0.1	K0III
λ	Cyg	3.75	4.24	4.23	3.81	3.84	3.75	4.45	4.53	−1.3	B6IV
μ	Cyg	—	—	—	—	3.84	3.75	4.11	4.49	—	—
ν	Cyg	3.75	3.91	3.90	3.81	3.84	—	3.78	3.94	0.9	A1Vn
ξ	Cyg	3.75	3.91	3.90	3.48	3.84	3.75	3.78	3.72	—	K4.5Ib-II+A2
$o1$	Cyg	4.08	3.91	—	—	—	3.75	3.78	3.79	−2.6	K2II+B4V
$o2$	Cyg	4.08	3.91	3.90	3.81	3.84	4.75	3.78	3.95	−2.3	K3II+B9:V
$\pi1$	Cyg	—	—	—	—	—	3.75	4.45	4.66	−2.6	B3IV
$\pi2$	Cyg	—	—	—	—	—	4.75	4.11	4.18	−3.2	B3III
ρ	Cyg	—	—	—	—	3.84	3.75	4.11	3.99	0.3	G8III
σ	Cyg	3.75	3.91	3.90	—	3.84	3.75	4.11	4.23	−6.8	B9Iab
τ	Cyg	3.75	3.91	3.57	4.14	3.84	3.75	—	3.72	2.0	F1IV
υ	Cyg	—	—	—	—	4.84	4.75	—	4.43	−2.5	B2Vne
ϕ	Cyg	5.08	5.58	5.57	4.81	4.84	4.75	4.78	4.69	1.5	G8III-IV
ψ	Cyg	—	—	—	—	4.84	4.75	4.78	4.92	1.9	A4Vn
$\omega1$	Cyg	—	—	—	—	—	4.75	4.78	4.94	−2.6	B2.5IV
$\omega2$	Cyg	—	—	—	—	4.84	4.75	5.45	5.44	−1.1	M2III
13	Del	—	—	—	—	—	—	5.78	5.58	0.6	A0V
14	Del	—	—	—	—	—	—	5.78	6.33	0.9	A1Vs
15	Del	—	—	—	—	—	—	5.78	5.98	3.4	F5V
16	Del	—	—	—	—	—	—	5.45	5.58	1.6	A4V
17	Del	—	—	—	—	—	—	5.45	5.17	0.2	K0III
18	Del	—	—	—	—	—	—	5.45	5.48	0.4	G6III:
α	Del	3.41	3.24	3.23	2.81	2.84	2.75	3.45	3.77	−0.1	B9V
β	Del	3.41	3.24	3.23	2.81	2.84	3.75	3.11	3.63	1.8	F5IV
γ	Del	3.41	3.24	3.23	2.81	2.84	2.75	3.11	3.87	—	—
δ	Del	3.41	3.24	3.23	2.81	2.84	3.08	3.78	4.43	1.2	?
ε	Del	3.41	3.58	3.57	2.81	2.84	2.75	3.78	4.03	−1.9	B6III
ζ	Del	6.08	5.91	5.90	4.48	3.84	4.75	4.45	4.68	1.7	A3V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
η	Del	6.08	5.91	5.90	5.81	4.84	5.75	5.45	5.38	0.9	A3IVs
θ	Del	6.08	5.91	5.90	5.81	4.84	5.75	5.78	5.72	−3.6	K3Ib
ι	Del	4.41	5.91	5.90	5.81	4.84	5.75	5.78	5.40	1.1	A2V
κ	Del	4.08	5.91	5.90	6.14	4.84	5.75	5.11	5.05	—	G5IV+K2IV
3	Dra	—	—	—	—	—	—	5.11	5.30	−0.1	K3III
4	Dra	—	—	—	—	—	—	4.78	4.95	−1.2	M4III
7	Dra	—	—	—	—	—	—	5.78	5.43	−0.4	K5III
8	Dra	—	—	—	—	—	—	4.78	5.24	2.9	A5n
9	Dra	—	—	—	—	—	—	5.78	5.32	0.1	K2III
10i	Dra	4.08	4.58	4.57	4.81	3.84	4.75	4.78	4.65	−1.0	M3.5III
15A	Dra	—	—	—	3.14	3.84	3.75	4.78	4.97	−0.6	A0III
18g	Dra	5.08	4.91	4.90	5.14	3.84	4.75	5.11	4.83	—	K1p
19h	Dra	5.08	4.91	4.90	5.14	3.84	5.75	4.78	4.89	3.7	F6Vvar
27f	Dra	6.08	5.91	5.90	—	3.84	4.75	5.11	5.05	−0.1	K0III
34	Dra	—	—	—	—	—	—	5.78	5.48	−1.0	F2.5II-III
35	Dra	—	—	—	—	—	—	4.78	5.04	2.9	F6IV-Vs
36	Dra	—	—	—	—	—	—	4.78	5.03	5.4	F5V
37	Dra	—	—	—	—	—	—	5.78	5.95	0.1	K1III:
39b	Dra	4.08	4.91	4.90	4.48	3.84	4.75	4.78	4.95	1.4	A3V
40	Dra	—	—	—	—	—	—	4.78	6.05	—	F7
41	Dra	—	—	—	—	—	—	4.78	5.68	—	F7
42	Dra	—	—	—	—	—	—	4.78	4.82	0.1	K2III
45d	Dra	4.08	4.91	4.90	4.48	3.84	4.75	4.78	4.80	−4.4	F7Ib
46c	Dra	4.08	4.91	4.90	4.48	3.84	4.75	5.11	5.04	—	B9.5p(Hg)
48	Dra	—	—	—	—	—	—	5.78	5.66	0.1	K1III
49	Dra	—	—	—	—	—	—	5.78	5.48	—	G5.5IIb
50	Dra	—	—	—	—	—	—	5.78	5.35	0.9	A1Vn
51	Dra	—	—	—	—	—	—	5.45	5.38	0.3	A0Vn
53	Dra	—	—	—	—	—	—	5.45	5.12	0.3	G8III
59	Dra	—	—	—	—	—	—	5.45	5.13	3.4	A9V
64e	Dra	—	—	—	4.81	3.84	5.08	5.45	5.27	−0.8	M1III
66	Dra	—	—	—	—	—	—	5.78	5.39	−0.1	K3III
68	Dra	—	—	—	—	—	—	5.78	5.70	3.4	F5V
71	Dra	—	—	—	—	—	—	5.78	5.72	−0.1	B9V
73	Dra	—	—	—	—	—	—	5.11	5.20	—	A0pSrCrEu
75	Dra	—	—	—	—	—	—	5.78	5.46	0.3	G9III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
76	Dra	—	—	—	—	—	—	5.78	5.68	0.3	A0V
α	Dra	3.08	3.24	3.23	2.14	1.84	1.75	3.11	3.65	−0.9	A0III
β	Dra	3.08	3.24	3.23	2.81	2.84	2.08	2.45	2.79	−2.0	G2II
γ	Dra	3.08	2.58	2.23	2.48	2.84	1.75	2.11	2.23	−0.4	K5III
δ	Dra	4.08	3.58	3.90	3.14	2.84	3.08	2.78	3.07	0.3	G9III
ε	Dra	4.08	4.24	3.57	3.14	2.84	5.08	3.78	3.83	0.0	G8III
ζ	Dra	3.08	2.91	2.90	2.81	2.84	1.75	2.78	3.17	−1.9	B6III
η	Dra	3.08	2.91	2.90	2.81	2.84	2.75	2.45	2.74	0.9	G8III
θ	Dra	3.75	3.91	3.90	3.14	2.84	2.75	3.45	4.01	2.3	F8IV-V
ι	Dra	3.08	3.24	3.23	2.81	2.84	2.75	2.78	3.29	0.1	K2III
κ	Dra	3.08	3.24	3.23	2.81	2.84	2.75	3.11	3.87	−2.2	B6IIIp
λ	Dra	3.08	3.24	3.23	2.81	2.84	3.08	3.11	3.84	—	M0IIIvar
μ	Dra	4.08	4.91	4.90	4.14	3.84	4.42	4.45	5.05	—	—
ξ	Dra	4.08	3.58	3.57	3.81	3.84	2.75	3.11	3.75	0.1	K2III
o	Dra	4.08	4.91	4.90	4.14	3.84	3.75	4.45	4.66	0.5	G9IIIb
π	Dra	4.08	2.58	3.23	3.81	3.84	3.75	4.78	4.59	−0.2	A2IIIs
ρ	Dra	4.08	4.58	4.57	3.81	3.84	4.75	4.78	4.51	−0.1	K3III
σ	Dra	5.08	4.58	4.57	3.48	3.84	4.08	5.11	4.70	5.9	K0V
τ	Dra	5.08	4.58	4.57	4.14	3.84	4.08	4.78	4.45	−0.4	K3III
υ	Dra	5.08	4.58	4.57	3.81	3.84	4.08	5.11	4.82	−0.1	K0III
ϕ	Dra	4.08	3.58	3.90	3.81	3.84	4.75	4.11	4.22	—	A0p(Si)
χ	Dra	4.08	3.91	3.90	3.81	3.84	3.75	3.45	3.57	4.1	F7Vvar
ψ	Dra	4.08	3.91	3.90	—	—	—	4.11	4.56	2.9	F5IV-V
ω	Dra	6.08	—	5.90	3.81	3.84	3.75	4.78	4.80	3.1	F5V
1	Equ	—	—	—	—	—	—	4.78	5.23	0.4	F5III
2	Equ	—	—	—	—	—	—	5.78	6.6	—	F8
3	Equ	—	—	—	—	—	—	5.78	5.61	−0.4	K5III
4	Equ	—	—	—	—	—	—	5.78	5.90	4.0	F8V
9	Equ	—	—	—	—	—	—	5.78	5.82	−1.1	M2III
α	Equ	—	3.91	3.90	3.81	3.84	3.75	3.78	3.92	−0.9	G2II-III+A4V
β	Equ	—	5.91	5.90	3.81	3.84	3.75	4.78	5.16	1.4	A3V
γ	Equ	—	5.24	5.23	3.81	3.84	3.75	4.45	4.69	—	F0p
δ	Equ	—	5.24	5.23	3.81	3.84	3.75	4.45	4.49	3.1	F8Vcomp
4	Eri	—	—	—	—	—	—	4.78	5.45	2.1	A5V
5	Eri	—	—	—	—	—	—	5.11	5.55	0.1	B9.5V
14	Eri	—	—	—	—	—	—	5.78	6.14	2.8	F1V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
15	Eri	—	—	—	—	—	—	5.11	4.88	0.4	G6III
17	Eri	—	—	—	—	—	—	4.78	4.74	0.2	B9Vs
20	Eri	—	—	—	—	—	—	4.78	5.23	−0.1	B9p
22	Eri	—	—	—	—	—	—	5.78	5.53	−0.8	B9IIIpSi4200
24	Eri	—	—	—	—	—	—	5.78	5.25	−0.9	B7V
30	Eri	—	—	—	—	—	—	5.45	5.48	−0.2	B8V
32	Eri	—	—	—	—	—	—	4.78	4.79	0.0	G8III
35	Eri	—	—	—	—	—	—	5.11	5.28	−1.1	B5V
39A	Eri	—	—	—	—	4.84	4.75	4.78	4.86	−0.1	K3III
41	Eri	—	—	3.57	—	—	—	—	3.56	−0.1	B9V
43	Eri	—	—	3.90	—	—	—	—	3.96	−0.2	K4III
45	Eri	—	—	—	—	—	—	5.11	4.91	−1.1	K3II-III
46	Eri	—	—	—	—	—	—	5.45	5.72	−1.2	B9pSi
47	Eri	—	—	—	—	—	—	5.45	5.11	−1.1	M3III
51c	Eri	—	—	—	—	5.84	3.75	5.11	5.21	2.6	F0V
54	Eri	—	—	—	—	—	—	4.78	4.32	−0.9	M4III
55	Eri	—	—	—	—	—	—	5.78	6.01	—	—
56	Eri	—	—	—	—	—	—	5.78	5.90	−2.5	B2Ve
58	Eri	—	—	—	—	—	—	5.78	5.50	4.6	G2.5V
60	Eri	—	—	—	—	—	—	5.78	5.03	—	K0IIIvar
62b	Eri	—	—	—	—	5.84	5.75	5.78	5.51	−0.9	B6V
63	Eri	—	—	—	—	—	—	5.78	5.38	5.0	G4V
64	Eri	—	—	—	—	—	—	5.78	4.79	1.7	F0IV
68	Eri	—	—	—	—	—	—	5.78	5.10	3.2	F2V
β	Eri	4.08	3.91	3.90	3.14	2.84	—	2.78	2.79	0.9	A3IIIvar
γ	Eri	3.08	3.24	3.23	2.81	2.84	1.75	2.78	2.97	−0.7	M0.5III
δ	Eri	3.08	3.24	3.23	2.81	2.84	3.08	2.78	3.51	3.7	K0IV
ε	Eri	3.08	3.24	3.23	2.81	2.84	3.08	2.78	3.73	6.1	K2V
ζ	Eri	3.08	3.91	3.90	—	2.84	2.75	4.11	4.80	—	A5m
η	Eri	3.08	3.58	3.57	—	2.84	2.75	2.78	3.89	—	K1III-IV
θ	Eri	1.08	0.91	—	—	2.84	—	—	2.83	—	—
ι	Eri	—	—	—	—	2.84	—	—	4.11	0.2	K0III
κ	Eri	—	—	—	—	2.84	—	—	4.20	−1.6	B5IV
λ	Eri	3.75	3.91	3.90	3.81	3.84	3.75	3.78	4.25	−3.0	B2IVn
μ	Eri	4.08	3.91	3.90	3.81	3.84	3.75	3.45	4.00	−1.9	B5IV
ν	Eri	4.08	3.91	3.90	3.81	3.84	3.75	3.11	3.93	−3.9	B2III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
ξ	Eri	5.08	5.24	5.23	—	3.84	3.42	5.11	5.17	1.4	A2V
$o1$	Eri	4.08	3.91	3.90	—	—	—	4.11	4.04	−0.7	F2II-III
$o2$	Eri	4.08	3.91	3.90	—	—	—	4.45	4.41	5.9	K1V
π	Eri	4.08	3.91	3.90	—	3.84	3.75	4.45	4.42	−1.1	M2III
$\rho1$	Eri	—	—	—	—	—	5.75	—	5.71	−2.0	K0II
$\rho2$	Eri	—	—	—	—	—	4.75	—	5.32	−0.9	K0II-III
$\rho3$	Eri	—	—	—	—	—	3.75	5.78	5.30	2.4	A8V
$\tau1$	Eri	4.08	3.91	3.90	—	—	3.75	4.11	4.50	3.6	F6V
$\tau2$	Eri	4.08	4.24	4.23	—	—	3.75	4.45	4.75	0.2	K0III
$\tau3$	Eri	4.08	3.58	3.57	—	—	—	3.45	4.10	2.6	A4IV
$\tau4$	Eri	4.08	3.91	3.90	—	—	—	3.45	3.66	−1.1	M3III
$\tau5$	Eri	4.08	3.91	3.90	—	—	—	3.78	4.30	−1.0	B8V+B8V
$\tau6$	Eri	4.08	3.91	3.90	—	—	—	3.78	4.20	2.8	F3III
$\tau7$	Eri	5.08	5.24	5.23	—	—	—	4.78	5.24	0.7	A2
$\tau8$	Eri	4.08	3.91	3.90	—	3.84	—	3.78	4.60	−1.2	B6V
$\tau9$	Eri	4.08	3.91	3.90	—	—	—	3.78	4.66	−1.2	B6V+B9.5V
$\upsilon1$	Eri	4.08	4.24	4.23	—	—	3.75	3.78	4.51	0.2	K0III
$\upsilon2$	Eri	4.08	3.91	3.90	—	3.84	2.75	3.45	3.82	0.3	G8III
ϕ	Eri	—	—	—	—	3.84	—	—	3.60	−0.4	B8IV-V
χ	Eri	—	—	—	—	3.84	—	—	3.70	2.3	G5IV
ψ	Eri	4.08	4.24	4.23	4.81	4.84	4.75	4.45	4.81	−1.7	B3V
ω	Eri	4.08	4.24	4.23	4.81	4.84	4.75	4.11	4.40	−0.2	F4III+A6III
1H	Gem	4.08	4.24	4.23	3.81	—	4.75	4.78	4.15	0.1	G5III
26	Gem	—	—	—	—	—	—	5.45	5.21	1.1	A2V
28	Gem	—	—	—	—	—	—	5.78	5.44	−0.2	K4III
30	Gem	—	—	—	—	—	—	4.78	4.49	0.1	K1III
33	Gem	—	—	—	—	—	—	5.78	5.87	−1.6	B7III
36d	Gem	5.08	5.24	5.23	5.81	5.84	5.75	5.78	5.27	1.4	A2V
38e	Gem	—	—	—	5.81	5.84	5.75	4.78	4.65	2.3	F0Vp
41	Gem	—	—	—	—	—	—	5.78	5.68	−5.7	K4Iab:
45	Gem	—	—	—	—	—	—	5.78	5.44	0.3	G8III
47	Gem	—	—	—	—	—	—	5.78	5.60	1.0	A4IV
51	Gem	—	—	—	—	—	—	5.78	5.00	−0.9	M4III
56q	Gem	—	—	—	—	—	6.08	5.45	5.10	−0.7	M0III
57A	Gem	5.08	5.24	5.23	5.81	5.84	5.08	5.11	5.03	0.3	G8III
58	Gem	5.08	4.91	—	—	—	—	5.78	6.02	1.2	A1V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
61	Gem	—	—	—	—	—	—	5.78	5.93	2.7	F2Vn
63p	Gem	—	—	—	—	—	5.75	5.45	5.24	2.5	F5IV-V
64b1	Gem	—	—	—	5.81	5.84	5.75	4.78	5.00	1.9	A4V
65b2	Gem	—	—	—	—	—	5.75	4.78	5.01	−0.2	K2III
68k	Gem	—	—	—	—	—	5.75	5.45	5.25	1.2	A1Vn
70	Gem	—	—	—	—	—	—	5.78	5.56	0.2	K0III
74f	Gem	5.08	5.24	5.23	—	5.84	5.75	5.78	4.80	−1.7	B3V
76c	Gem	—	—	—	—	5.84	5.75	5.78	5.31	−0.4	K5III
81g	Gem	5.08	5.24	5.23	—	5.84	5.75	5.45	4.90	−0.7	K5III
85l	Gem	5.08	5.24	5.23	—	—	5.75	5.45	5.35	0.3	A0Vn
α	Gem	2.08	1.91	1.90	1.81	1.84	0.75	1.45	1.57	—	—
β	Gem	2.08	1.91	1.90	1.81	1.84	1.75	1.11	1.15	1.0	K0IIIvar
γ	Gem	3.08	2.91	2.90	1.81	1.84	2.08	2.11	1.90	−0.3	A0IV
δ	Gem	3.08	3.58	2.90	2.81	2.84	2.75	3.11	3.53	2.4	F0IV
ε	Gem	3.08	3.24	3.23	2.81	2.84	2.75	3.11	2.98	—	G8Ibvar
ζ	Gem	3.08	2.91	3.57	2.81	2.84	3.08	3.78	3.79	−4.3	G3Ib
η	Gem	3.75	3.58	3.57	3.81	2.84	4.08	2.78	3.28	−1.4	M3III
θ	Gem	4.08	3.58	3.57	4.81	3.84	3.75	3.11	3.60	−0.3	A3III
ι	Gem	4.08	3.91	3.90	3.81	3.84	4.08	3.78	3.79	—	G9IIIcomp
κ	Gem	4.08	3.58	3.57	3.81	3.84	4.08	3.45	3.57	0.3	G8III
λ	Gem	3.08	3.24	3.23	3.81	3.84	4.75	3.45	3.57	1.6	A3V
μ	Gem	3.75	3.58	3.57	2.81	3.84	2.75	—	2.88	—	M3IIIvar
ν	Gem	3.75	3.24	3.23	3.81	3.84	3.75	4.45	4.14	−2.2	B6III
ξ	Gem	4.08	3.91	3.90	3.81	3.84	—	3.45	3.40	1.9	F5IV
o	Gem	—	—	—	—	4.84	5.75	5.11	4.90	0.6	F3III
π	Gem	—	—	—	—	4.84	4.75	5.78	5.14	−0.7	M0III
ρ	Gem	—	—	—	4.81	4.84	4.75	4.78	4.16	3.0	F0V
σ	Gem	—	—	—	4.81	4.84	4.75	4.78	4.28	−0.2	K1III
τ	Gem	4.08	3.91	3.90	3.81	4.84	4.75	4.45	4.42	0.1	K2III
υ	Gem	4.08	3.91	3.90	4.81	4.84	4.75	4.11	4.06	−0.4	K5III
ϕ	Gem	—	—	—	5.81	4.84	4.75	4.78	5.00	1.4	A3V
χ	Gem	—	—	—	—	4.84	—	4.78	4.94	−0.2	K2III
ω	Gem	—	—	—	—	5.84	—	5.78	5.18	−1.9	G5III
γ	Gru	4.08	3.24	—	—	—	—	—	3.01	−1.2	B8III
2	Her	—	—	—	—	—	—	5.78	5.37	−1.1	M3IIIBa0.3
4	Her	—	—	—	—	—	—	5.78	5.75	—	B9pe

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
5r	Her	—	—	—	—	5.84	2.75	5.45	5.12	0.3	G8III
9	Her	—	—	—	—	—	—	5.78	5.48	−0.4	K5III
10	Her	—	—	—	—	—	—	5.78	5.58	−0.9	M4III
21o	Her	—	—	—	—	—	—	5.78	5.85	—	A2p(Sr)
25	Her	—	—	—	—	—	—	5.45	5.50	2.1	A5V
28n	Her	—	—	—	—	5.84	—	5.78	5.64	−0.7	B9.5III
29h	Her	—	—	—	—	5.84	3.75	5.11	4.84	−0.2	K4III
30g	Her	—	—	—	4.81	4.84	4.75	5.11	5.01	—	M6III:var
37m2	Her	—	—	—	—	5.84	—	—	5.77	1.2	A1V
42	Her	—	—	—	—	—	—	4.45	4.90	−1.1	M2.5III
43i	Her	—	—	—	—	5.84	—	5.45	5.15	−0.4	K5III
45l	Her	—	—	—	—	5.84	—	5.78	5.24	1.0	B9p(Cr)
47k	Her	—	—	—	—	—	4.75	5.45	5.49	—	A3m
49	Her	—	—	—	—	—	—	5.78	6.52	—	B9.5p(Cr)
50	Her	—	—	—	—	—	—	5.78	5.72	−0.8	M1III
51	Her	—	—	—	—	—	—	5.78	5.04	−1.0	K2II-III
52	Her	—	—	—	—	—	—	4.11	4.79	2.2	A2pSrCrEu
53	Her	—	—	—	—	—	—	4.78	5.30	2.8	F1V
54	Her	—	—	—	—	—	—	5.78	5.35	−0.2	K4III
59d	Her	5.08	5.24	5.23	—	4.84	5.75	4.78	5.25	0.9	A3IV
60	Her	—	—	—	—	—	—	4.78	4.91	1.0	A4IV
61c	Her	3.08	5.24	5.23	—	4.84	5.75	4.78	6.69	−0.9	M4III
63	Her	—	—	—	—	—	—	5.78	6.19	1.7	A8V
68u	Her	—	—	—	—	5.84	4.75	4.78	4.77	−3.3	B1.5Vp
69e	Her	4.08	4.91	4.90	3.81	4.84	—	4.78	4.65	1.1	A2V
70	Her	—	—	—	—	—	—	5.78	5.12	1.1	A2V
72w	Her	—	—	—	—	5.84	5.75	5.11	5.40	4.7	G0V
73	Her	—	—	—	—	—	—	5.78	5.70	1.7	F0IV
74x(?)	Her	6.08	5.91	5.90	—	—	—	—	5.59	−0.7	M0III
77y,77x	Her	6.08	5.91	5.90	—	5.84	—	5.78	5.80	1.6	A4V
78	Her	—	—	—	—	—	—	5.78	5.62	1.2	A1V
79	Her	—	—	—	—	—	—	5.78	5.62	1.4	A2Vn
82x,82y	Her	6.08	5.91	5.90	—	5.84	—	5.78	5.37	0.1	K1III
84	Her	—	—	—	—	—	—	5.78	5.71	—	G2IIIb
87	Her	—	—	—	—	—	—	5.78	5.12	0.1	K2III
88z(?)	Her	—	—	—	—	5.84	5.75	5.78	6.68	—	Bep,shell

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
89	Her	—	—	—	—	—	—	5.78	5.46	—	F2Iavar
90f	Her	—	—	—	—	4.84	5.75	4.78	5.16	—	K2II-III+(A5V)
93	Her	—	—	—	—	—	—	4.78	4.67	−0.9	K0II-III
95	Her	—	—	—	—	—	—	4.11	4.31	—	—
96	Her	—	—	—	—	—	—	4.78	5.27	−2.6	B3IV
98	Her	—	—	—	—	—	—	5.78	5.06	−1.7	M3IIIaBa0.2ZrO
99b	Her	—	—	—	—	4.84	4.75	4.78	5.04	3.9	F7V
100	Her	—	—	—	—	—	—	5.11	5.13	—	—
101	Her	—	—	—	—	—	—	4.78	5.10	0.5	A8III
102	Her	—	—	—	—	—	—	4.11	4.35	−3.0	B2IV
104A	Her	—	—	—	—	4.84	4.08	4.78	4.97	−1.1	M3III
105	Her	—	—	—	—	—	—	5.78	5.27	−2.6	K4II
106	Her	—	—	—	—	—	—	5.78	4.95	−1.1	M1III
107t	Her	—	—	—	—	5.84	5.75	4.78	5.12	2.1	A7V
108	Her	—	—	—	—	—	—	5.11	5.63	—	A5m
109	Her	—	—	—	—	—	—	3.78	3.84	0.1	K2III
110	Her	—	—	—	—	—	—	3.78	4.20	2.7	F6V
111	Her	—	—	—	—	—	—	4.11	4.36	0.3	A5III
112	Her	—	—	—	—	—	—	4.78	5.48	—	B9pHg
113	Her	—	—	—	—	—	—	4.11	4.53	—	—
α	Her	3.08	3.24	3.23	2.48	2.84	2.75	—	3.31	—	—
β	Her	3.08	2.91	2.90	2.81	2.84	2.75	2.11	2.77	0.0	G8III
γ	Her	3.08	3.24	3.23	3.14	2.84	2.75	2.78	3.75	0.3	A9III
δ	Her	3.08	2.91	2.90	—	2.84	3.75	2.78	3.14	0.6	A3IV
ε	Her	5.08	3.91	3.90	2.81	2.84	2.75	3.11	3.92	0.3	A0V
ζ	Her	3.08	2.91	2.90	2.81	2.84	2.75	2.45	2.71	—	—
η	Her	3.75	3.91	3.90	2.81	2.84	2.75	2.78	3.53	2.2	G8III-IV
θ	Her	4.08	3.91	3.90	2.81	2.84	3.75	3.78	3.82	—	K1IIvar
ι	Her	4.08	3.91	3.90	2.81	3.84	3.75	3.11	3.80	−2.0	B3V
κ	Her	4.08	4.24	4.23	3.48	3.84	—	4.78	4.70	—	—
λ	Her	3.75	4.91	4.90	4.14	3.84	4.08	4.78	4.41	—	K3IIIvar
μ	Her	3.75	3.91	3.90	3.48	—	3.75	3.11	3.41	3.8	G5IV
ν	Her	3.75	3.91	3.90	4.14	3.84	4.75	4.11	4.41	—	F2II+B9.5
ξ	Her	4.08	3.91	3.90	4.14	3.84	3.75	3.45	3.70	0.2	K0III
o	Her	3.75	3.91	3.90	4.14	3.84	—	3.45	3.84	0.1	B9.5V
π	Her	4.08	3.58	3.57	3.81	3.84	3.08	3.11	3.16	—	K3IIvar

	star	137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
ρ	Her	3.75	3.91	3.90	3.81	3.84	3.75	3.78	4.15	—	—
σ	Her	4.08	3.91	3.90	3.81	3.84	3.75	3.78	4.20	—	B9Vvar
τ	Her	3.75	3.58	3.57	3.81	3.84	3.75	3.11	3.89	−1.6	B5IV
υ	Her	4.08	3.91	3.90	3.81	3.84	4.75	4.11	4.71	−0.8	B9III
ϕ	Her	4.08	3.91	3.90	3.81	3.84	5.75	3.78	4.26	—	B9pMn
χ	Her	4.08	4.91	4.90	3.48	3.84	5.75	4.11	4.62	3.4	F9V
ω	Her	5.08	3.91	3.90	—	4.84	5.75	4.78	4.57	—	B9pCr
6	Hya	—	—	—	—	5.84	—	5.78	4.98	−0.2	K4III
9	Hya	—	—	—	—	—	—	5.78	4.88	0.3	G8III
12	Hya	—	—	—	—	—	—	4.45	4.32	0.0	G8III
14	Hya	—	—	—	—	—	—	5.78	5.31	−0.4	B9pHgMn
15	Hya	—	—	—	—	—	—	5.78	5.54	1.0	A4m
20	Hya	—	—	—	—	—	—	5.78	5.46	−1.9	G8II
21	Hya	—	—	—	—	—	—	5.78	6.11	−0.5	A3III+A0V:
23	Hya	—	—	—	—	—	—	5.78	5.24	−0.2	K2III
24	Hya	—	—	—	—	—	—	5.78	5.49	−0.8	B9III
26	Hya	—	—	—	—	—	—	5.78	4.79	0.3	G8III
27	Hya	—	—	—	—	—	—	5.78	4.8	3.1	F5Vcomp
28	Hya	—	—	—	—	—	—	5.78	5.59	−0.4	K5III
33A	Hya	—	—	—	—	5.84	5.75	5.78	5.56	0.1	K1III
37	Hya	—	—	—	—	—	—	5.78	6.31	0.6	A0Vn
44	Hya	—	—	—	—	—	—	5.78	5.08	−0.2	K4III
47	Hya	—	—	—	—	—	—	5.78	5.15	−0.5	B8Vpsh
50	Hya	—	—	—	—	—	—	5.45	5.08	0.1	K2III
51	Hya	—	—	—	—	—	—	5.45	4.77	−0.1	K3III
52	Hya	—	—	—	—	—	—	5.45	4.97	−0.4	B7/B8V
54	Hya	—	—	—	—	—	—	5.78	4.94	3.0	F2III-IV
58	Hya	—	—	—	—	—	—	5.45	4.42	−0.1	K3III
α	Hya	2.08	1.91	1.90	1.14	1.84	1.75	1.78	1.98	−0.1	K3III
β	Hya	3.08	2.91	2.90	—	2.84	3.75	3.78	4.28	−0.8	ApSi
γ	Hya	3.75	2.91	3.23	—	2.84	2.75	2.78	3.00	—	G5IIIvar
δ	Hya	4.08	3.91	4.23	3.81	3.84	3.75	4.11	4.16	0.9	A1Vnn
ε	Hya	4.08	3.91	3.90	3.81	3.84	3.75	3.11	3.08	—	—
ζ	Hya	4.08	3.58	3.57	3.81	3.84	3.75	3.11	3.11	1.7	G8III-IV
η	Hya	4.08	4.91	3.90	3.81	3.84	3.75	4.45	4.30	—	B3V
θ	Hya	4.08	4.24	3.90	3.81	3.84	3.75	3.78	3.88	0.1	B9.5V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
ι	Hya	4.08	4.24	4.23	3.81	3.84	3.75	4.11	3.91	—	K3IIIvar
κ	Hya	4.08	3.91	—	3.81	3.84	4.08	4.78	5.04	−1.1	B5V
λ	Hya	—	—	3.57	—	3.84	3.75	3.78	3.61	−0.1	K0III
μ	Hya	3.08	3.24	3.23	—	3.84	3.75	3.78	3.81	−0.5	K7III
ν	Hya	3.08	2.91	2.90	—	3.84	—	3.11	3.11	0.1	K2III
ξ	Hya	4.08	3.58	3.57	—	3.84	—	3.78	3.54	0.3	G8III
o	Hya	4.08	3.58	3.90	—	3.84	—	—	4.70	0.2	B9V
π	Hya	3.75	3.24	3.23	—	3.84	3.75	3.45	3.27	0.1	K2III
ρ	Hya	—	—	—	4.81	4.84	4.75	4.78	4.36	0.3	A0Vn
σ	Hya	4.08	4.24	4.23	4.81	4.84	4.75	4.78	4.44	0.1	K2III
$\tau1$	Hya	4.08	4.24	4.23	4.81	—	4.75	4.78	4.60	3.7	F6V
$\tau2$	Hya	4.08	4.24	4.23	4.81	—	4.75	4.78	4.60	1.4	A3V
$\upsilon1$	Hya	4.08	3.91	3.90	—	—	4.75	4.45	4.12	0.3	G8III
$\upsilon2$	Hya	4.08	3.58	3.90	—	—	4.75	4.45	4.60	−0.8	B9III-IV
ϕ	Hya	4.08	4.24	4.23	—	—	—	4.78	4.91	−0.1	K0III
$\phi2$	Hya	—	—	—	—	—	5.75	—	6.03	−0.8	M1III
$\chi1$	Hya	4.08	3.91	3.90	—	—	—	—	4.94	2.5	F3IV/V
ψ	Hya	—	—	—	—	4.84	5.75	5.11	4.95	0.1	K1III
ω	Hya	5.08	4.24	5.90	5.81	4.84	5.75	5.78	4.97	−1.0	K2II-III
1	Lac	—	—	—	—	—	—	4.45	4.13	−0.1	K3III
2	Lac	—	—	—	—	—	—	4.45	4.57	−1.2	B6V
3 (β)	Lac	—	—	—	—	—	—	4.45	4.43	0.3	G9III
4	Lac	—	—	—	—	—	—	4.78	4.56	−6.5	B9Iab
5	Lac	—	—	—	—	—	—	4.78	4.36	−2.7	M0II+B8V
6	Lac	—	—	—	—	—	—	4.78	4.53	−3.3	B2IV
7 (α)	Lac	—	—	—	—	—	—	3.78	3.77	1.2	A1V
8	Lac	—	—	—	—	—	—	5.78	4.97	—	—
9	Lac	—	—	—	—	—	—	4.78	4.63	1.2	A8IV
10	Lac	—	—	—	—	—	—	4.78	4.90	−4.8	O9V
11	Lac	—	—	—	—	—	—	4.78	4.46	−0.1	K3III
12	Lac	—	—	—	—	—	—	5.78	5.26	−3.9	B2III
13	Lac	—	—	—	—	—	—	5.78	5.08	0.2	K0IIIvar
14	Lac	—	—	—	—	—	—	5.78	5.93	—	B3IV:var
15	Lac	—	—	—	—	—	—	5.78	4.94	−0.7	M0III
16	Lac	—	—	—	—	—	—	5.78	5.59	−3.3	B2IV
3	Leo	—	—	—	—	—	—	5.78	5.71	0.2	K0III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
6h	Leo	—	—	—	—	5.84	5.75	5.78	5.14	−0.4	K3III
7h(?)	Leo	—	—	4.90	—	—	—	—	6.36	1.2	A1V
8	Leo	—	—	—	—	—	—	5.78	5.69	0.1	K1III
15f	Leo	—	—	—	—	5.84	5.75	4.78	5.60	0.6	A2IV
18	Leo	—	—	—	—	—	—	5.78	5.63	−0.2	K4III
22g	Leo	—	—	—	—	5.84	5.75	4.78	5.32	1.2	A5IV
23k	Leo	—	—	4.90	—	—	—	—	6.46	−0.7	M0III
31A	Leo	4.08	3.91	3.90	4.81	4.84	4.75	4.78	4.37	−0.2	K4III
44	Leo	—	—	—	—	—	—	5.78	5.61	−1.1	M3III
45	Leo	—	—	—	—	—	—	5.78	6.04	—	A0pSi(Cr)
46i	Leo	6.08	3.91	5.90	—	5.84	5.75	5.78	5.46	−0.4	M1.5IIIb
48	Leo	—	—	—	—	—	—	5.78	5.08	−0.8	G8II-III
50	Leo	—	—	—	—	—	—	5.78	6.62	3.4	F5V
51m	Leo	—	—	—	—	5.84	5.75	5.78	5.49	−0.1	K3III
52k	Leo	6.08	5.91	5.90	5.81	5.84	5.75	5.78	5.48	0.4	G4III:
53l	Leo	6.08	5.91	5.90	5.81	5.84	5.75	4.78	5.25	1.1	A2V
54	Leo	5.08	4.91	4.90	—	—	—	4.11	4.30	—	—
55	Leo	—	—	—	—	—	—	5.78	5.91	0.3	F2III
58d	Leo	5.08	4.91	4.90	—	4.84	5.42	4.78	4.85	0.1	K1III
59c	Leo	5.08	4.24	4.90	—	4.84	4.75	4.78	4.99	0.3	A5III
60b	Leo	6.08	4.58	5.57	4.81	4.84	4.75	4.11	4.42	—	A1m
61p2	Leo	—	—	—	—	—	—	4.78	4.74	−0.4	K5III
62p3	Leo	—	—	—	—	—	—	5.78	5.95	−0.1	K3III
65p4	Leo	—	—	—	—	—	—	5.78	5.52	0.3	G9IIICN−1
69s	Leo	—	—	3.90	—	5.84	—	4.78	5.42	0.6	A0V
67	Leo	—	—	—	—	—	—	5.78	5.68	0.9	A3IV
72	Leo	—	—	—	—	—	—	4.78	4.63	—	M3IIb
73n	Leo	—	—	—	—	5.84	5.75	5.78	5.32	−0.2	K3III+F1V
75	Leo	—	—	—	—	—	—	5.78	5.18	—	M0IIIcomp
79	Leo	—	—	—	—	—	—	5.78	5.39	0.3	G8IIICN−0.5
81	Leo	5.08	4.91	4.90	—	—	—	5.78	5.60	3.0	F2V
85	Leo	—	—	—	—	—	—	5.78	5.74	−0.2	K4III
86	Leo	—	—	—	—	—	—	5.78	5.52	0.2	K0III
87e	Leo	—	—	—	—	4.84	4.08	4.78	4.77	−0.2	K4III
88	Leo	—	—	—	—	—	—	5.78	6.20	4.4	G0V
89	Leo	—	—	—	—	—	—	5.78	5.70	3.4	F5V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
90	Leo	—	—	—	—	—	—	5.78	5.95	−1.7	B4V
92	Leo	—	—	—	—	—	—	4.78	5.26	0.1	K1III
93	Leo	—	—	—	—	—	—	4.11	4.60	1.3	G4III-IV+A7V
95o	Leo	—	—	—	—	5.84	5.75	5.78	5.50	1.4	A3V
α	Leo	1.08	0.91	0.90	0.81	0.84	0.75	1.11	1.35	−0.9	B7V
β	Leo	1.41	0.91	0.90	—	0.84	1.08	1.78	2.14	1.5	A3Vvar
γ	Leo	2.08	1.91	1.90	1.81	1.84	1.75	1.78	2.21	—	—
δ	Leo	2.41	4.91	1.90	1.81	1.84	2.08	2.11	2.56	1.9	A4V
ε	Leo	2.75	2.58	2.57	2.81	2.84	2.75	2.78	2.98	−2.0	G0II
ζ	Leo	3.08	2.91	2.90	2.81	2.84	2.75	2.78	3.40	0.3	F0III
η	Leo	3.08	2.91	2.90	2.81	2.84	3.08	3.11	3.49	−5.2	A0Ib
θ	Leo	3.08	2.91	2.90	2.81	2.84	2.75	3.11	3.34	1.4	A2V
ι	Leo	3.08	3.24	3.23	—	2.84	3.75	3.78	4.00	2.4	F2IV
κ	Leo	4.08	3.91	3.90	3.81	3.84	3.75	4.78	4.46	0.1	K2III
λ	Leo	4.08	3.91	3.90	3.81	3.84	3.75	4.45	4.31	—	K5IIIvar
μ	Leo	3.08	3.24	3.23	3.81	3.84	3.08	3.78	3.88	0.2	K0III
ν	Leo	5.08	4.91	4.90	3.81	3.84	4.08	4.78	5.26	−0.6	B9IV
ξ	Leo	5.08	5.91	5.90	3.81	3.84	3.75	5.78	4.97	—	K0IIIvar
o	Leo	4.08	3.58	3.57	3.81	3.84	—	3.45	3.52	−2.1	F6II+A1V
π	Leo	4.08	3.91	3.90	3.81	3.84	3.75	4.78	4.70	−1.1	M2III
ρ	Leo	4.08	3.91	3.90	3.81	3.84	3.75	3.78	3.85	−6.0	B1Ib
σ	Leo	4.08	3.91	3.57	—	3.84	4.08	3.78	4.06	0.1	B9.5Vs
τ	Leo	4.08	3.91	—	—	3.84	3.75	4.78	4.95	−0.8	G8II-III
υ	Leo	5.08	4.91	4.90	—	3.84	—	4.45	4.30	0.3	G9III
ϕ	Leo	—	—	—	—	3.84	3.75	4.45	4.50	1.5	A7IVn
χ	Leo	4.41	4.91	4.23	—	3.84	4.08	4.78	4.63	—	F2III-Ivvar
ψ	Leo	5.08	5.91	5.90	3.81	4.84	5.75	5.78	5.35	−1.1	M2III
ω	Leo	—	—	—	—	4.84	4.75	5.78	5.41	3.9	F9V
8	Lep	—	—	—	—	—	—	5.78	5.25	−3.0	B2IV
17	Lep	—	—	—	—	—	—	4.78	4.93	—	A2sh
α	Lep	3.08	3.24	3.23	3.14	2.84	2.75	2.78	2.58	−4.7	F0IV
β	Lep	3.08	3.24	3.23	2.81	2.84	2.75	3.11	2.84	−1.9	G5II
γ	Lep	3.75	3.58	3.57	3.14	2.84	3.08	3.78	3.60	4.0	F6V
δ	Lep	3.75	5.58	3.57	3.14	2.84	3.42	3.78	3.81	—	G8p
ε	Lep	3.75	3.58	3.57	3.81	3.84	3.75	3.45	3.19	—	K5IIIvar
ζ	Lep	3.75	—	3.57	—	3.84	3.75	3.45	3.60	1.7	A3Vn

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
η	Lep	3.75	3.58	3.57	3.81	3.84	3.75	3.45	3.70	2.6	F1III
θ	Lep	—	—	—	4.14	3.84	3.75	4.78	4.67	0.9	A1Vn
ι	Lep	5.08	4.91	4.90	4.81	4.84	4.75	4.78	4.44	−0.2	B8V
κ	Lep	5.08	4.91	4.90	4.81	4.84	4.75	4.11	4.36	0.2	B9V
λ	Lep	5.08	4.91	4.90	4.81	4.84	4.08	4.11	4.30	−4.2	B0.5IV
μ	Lep	3.75	3.58	3.57	4.81	4.84	3.75	3.11	3.31	−0.4	B9pHgMn
ν	Lep	5.08	4.91	4.90	5.81	5.84	5.08	5.45	5.30	−1.0	B7IVnn
11	Lib	—	—	—	—	—	—	5.78	4.94	—	G8comp
12	Lib	—	—	—	—	—	—	5.78	5.30	0.1	K2III
16	Lib	—	—	—	—	—	—	4.45	4.50	2.6	F0V
34	Lib	—	—	—	—	—	—	5.78	5.82	0.4	G6III:
37	Lib	5.08	4.91	4.90	—	—	—	4.78	4.61	—	K1IV
41	Lib	5.08	5.91	—	—	—	—	—	5.38	—	G8IIIvar
48	Lib	4.41	4.24	—	—	—	—	4.78	4.88	−2.2	B5IIIp
50	Lib	—	—	—	—	—	—	5.78	5.55	0.6	A0Vs
β	Lib	2.08	2.58	2.57	1.81	1.84	1.75	1.78	2.61	−0.5	B8V
γ	Lib	4.08	3.91	3.90	3.14	2.84	3.08	4.11	3.91	1.7	G8III-IV
δ	Lib	5.08	5.24	5.23	3.81	3.84	4.08	4.78	4.92	0.1	B9.5V
ε	Lib	—	—	—	4.14	3.84	3.75	4.78	4.94	1.8	F5IV
ζ	Lib	—	—	—	—	3.84	—	5.78	5.50	−2.8	B2Vn
η	Lib	—	—	—	—	3.84	3.75	5.78	5.41	1.7	F0IV
θ	Lib	4.41	3.91	3.90	—	3.84	3.75	4.45	4.15	1.7	K0III-IV
ι	Lib	4.08	3.91	3.90	—	—	—	4.45	4.54	—	A0pSi
κ	Lib	—	—	—	—	3.84	3.75	4.78	4.74	—	K5IIIvar
λ	Lib	6.08	5.91	5.90	—	3.84	3.75	5.78	5.03	−2.4	B2.5V
μ	Lib	5.08	5.24	5.23	4.81	4.84	4.75	5.78	5.6	—	A1pSrCrEu
ν	Lib	4.08	5.24	5.23	4.81	—	—	5.78	5.20	−0.4	K5III
ξ1	Lib	—	—	—	—	—	5.75	5.78	5.80	0.3	G7III
ξ2	Lib	—	—	—	—	—	5.75	5.78	5.46	−0.2	K4III
o	Lib	—	—	—	—	5.84	—	5.78	6.32	0.6	F0III
σ	Lib	3.08	3.24	3.23	—	—	—	—	3.29	2.0	M3.5III
τ	Lib	4.08	3.91	3.90	—	—	—	—	3.66	−2.4	B2.5V
υ	Lib	4.08	3.91	3.90	—	—	—	—	3.58	−0.1	K3III
8	LMi	—	—	—	—	—	—	5.78	5.37	−0.8	M1III
10	LMi	—	5.91	5.90	—	—	—	4.78	4.60	0.3	G8III
11	LMi	—	—	—	—	—	—	5.78	5.41	5.6	G8IV-V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
19	LMi	—	—	—	—	—	—	4.78	5.10	3.4	F6Vs
20	LMi	—	—	—	—	—	—	4.78	5.40	4.0	G1V
21	LMi	—	—	—	—	—	—	4.11	4.48	2.4	A7V
22	LMi	—	—	—	—	—	—	5.78	6.46	0.3	G8III
23	LMi	—	—	—	—	—	—	4.78	5.51	0.6	A0Vn
27	LMi	—	—	—	—	—	—	5.78	5.90	2.2	A6V
30	LMi	—	—	—	—	—	—	4.45	4.70	2.6	F0V
31(β)	LMi	—	—	—	—	—	—	4.11	4.21	—	G8III-IV+(F4V)
32	LMi	—	—	—	—	—	—	5.78	5.77	1.9	A4V
34	LMi	—	—	—	—	—	—	5.78	5.58	1.4	A2Vn
35	LMi	—	—	—	—	—	—	5.78	6.28	3.1	F3V
37	LMi	—	—	—	—	—	—	4.45	4.70	−2.0	G0II
38	LMi	—	—	—	—	—	—	5.78	5.85	3.9	F9V
40	LMi	—	—	—	—	—	—	5.78	5.51	1.9	A4Vn
41	LMi	5.08	4.91	4.90	—	—	—	4.78	5.08	1.7	A3Vn
42	LMi	—	—	—	—	—	—	4.78	5.24	0.9	A1Vn
46	LMi	—	—	—	—	—	—	3.78	3.83	1.7	K0III-IV
1i	Lup	3.75	5.91	5.90	—	—	—	—	4.91	0.6	F3III
2f	Lup	3.75	5.24	5.23	—	3.84	—	—	4.34	−1.0	K1II/III
α	Lup	3.08	2.91	2.90	—	2.84	—	—	2.30	−4.3	B1.5III
β	Lup	3.08	2.91	2.90	—	4.84	—	—	2.70	−3.9	B2III
γ	Lup	4.08	3.24	3.23	—	3.84	5.08	—	2.78	−3.0	B2IV
δ	Lup	4.08	—	3.57	—	3.84	5.08	4.45	3.20	−3.4	B1.5IV
ε	Lup	4.08	3.58	3.57	—	3.84	—	—	3.40	−3.0	B2IV-V
ζ	Lup	5.08	4.24	4.23	—	4.84	—	—	3.41	0.3	G8III
η	Lup	4.08	3.91	3.90	—	4.84	—	—	3.41	−2.6	B2.5IV
θ	Lup	3.75	4.91	4.90	—	4.84	—	—	4.20	−2.1	B2.5Vn
ι	Lup	4.08	4.24	4.23	—	3.84	—	—	3.55	−2.6	B2.5IV
κ	Lup	5.08	4.24	4.90	—	4.84	—	—	3.68	—	—
λ	Lup	5.08	4.91	4.90	—	4.84	4.75	4.78	4.05	−2.0	B3V
μ	Lup	5.08	4.91	4.90	—	—	—	—	4.27	−0.2	B8V
ξ	Lup	—	—	5.23	—	—	—	—	4.58	—	—
π	Lup	5.08	4.91	4.90	—	2.84	—	—	4.00	—	—
ρ	Lup	5.08	4.91	—	—	—	—	—	4.00	−1.1	B5V
χ	Lup	4.08	6.24	4.57	—	—	—	—	3.95	−0.7	B9.5III-IV
1	Lyn	—	—	—	—	—	—	5.78	4.98	−1.1	M3III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
2	Lyn	—	—	—	—	—	—	4.45	4.48	1.4	A2Vs
5	Lyn	—	—	—	—	—	—	5.78	5.23	−0.5	K4III
8	Lyn	—	—	—	—	—	—	5.78	5.90	4.4	G8IV-V
11	Lyn	—	—	—	—	—	—	5.78	5.85	1.4	A2V
12	Lyn	—	—	—	—	—	—	4.78	4.87	1.7	A3V
13	Lyn	—	—	—	—	—	—	5.78	5.35	0.2	K0III
14	Lyn	—	—	—	—	—	—	5.78	5.33	0.0	G5III:+A2V
15	Lyn	—	—	—	—	—	—	4.78	4.35	1.8	G5III-IV
18	Lyn	—	—	—	—	—	—	5.78	5.20	0.1	K2III
19	Lyn	—	—	—	—	—	—	4.78	5.01	—	—
21	Lyn	—	—	—	—	—	—	4.78	4.64	1.2	A1V
22	Lyn	—	—	—	—	—	—	5.78	5.40	3.6	F6V
24	Lyn	—	—	—	—	—	—	4.78	4.99	0.9	A3IVn
25	Lyn	—	—	—	—	—	—	5.78	6.25	0.1	K2III:
26	Lyn	—	—	—	—	—	—	5.78	5.45	−0.2	K4III
27	Lyn	—	—	—	—	—	—	4.45	4.84	1.4	A2V
29	Lyn	—	—	—	—	—	—	5.78	5.50	1.5	A7IV
31	Lyn	—	5.91	5.90	—	—	—	4.78	4.25	−0.4	K5III
33	Lyn	—	—	—	—	—	—	5.78	5.78	1.4	A2Vnn
34	Lyn	—	—	—	—	—	—	5.78	5.37	2.8	G0IV
35	Lyn	—	—	—	—	—	—	5.78	5.15	0.2	K0III
36	Lyn	—	—	—	—	—	—	4.78	5.28	−1.2	B8IIIpMn
38	Lyn	4.08	3.91	3.90	—	—	—	3.78	3.82	0.9	A1V
40(α)	Lyn	4.08	3.91	3.90	—	—	—	3.11	3.16	—	M0IIIvar
42	Lyn	—	—	—	—	—	—	5.78	5.20	2.6	F0V
43	Lyn	—	—	—	—	—	—	5.78	5.62	0.3	G8III
13	Lyr	—	—	—	—	—	—	4.45	4.04	—	M5IIIvar
16	Lyr	—	—	—	—	—	—	4.78	5.00	2.4	A7V
17	Lyr	—	—	—	—	—	—	5.11	5.23	2.3	F0V
19	Lyr	—	—	—	—	—	—	5.78	5.98	−1.4	B9pSi
γ	Lyr	3.08	2.91	2.90	2.81	2.84	2.75	3.11	3.24	−0.8	B9III
δ1	Lyr	—	—	—	—	—	4.08	—	5.57	−2.4	B2.5V
δ2	Lyr	—	—	3.90	4.14	3.84	3.75	—	4.30	—	M4IIvar
ζ	Lyr	3.75	3.58	3.57	4.48	4.84	4.75	4.11	4.12	—	—
η	Lyr	4.08	4.24	4.23	4.48	4.84	5.75	4.11	4.40	−2.9	B2.5IV
θ	Lyr	4.08	4.24	4.23	4.81	4.84	5.75	4.11	4.36	−2.0	K0II

	star	137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
ι	Lyr	—	—	—	4.81	4.84	4.75	4.78	5.28	−1.3	B6IV
κ	Lyr	—	—	—	—	4.84	—	4.45	4.33	—	K2IIIvar
λ	Lyr	4.41	4.91	5.23	5.81	5.84	5.75	3.11	4.93	−0.1	K3III
μ	Lyr	—	—	—	—	5.84	5.75	5.11	5.12	0.6	A3IVn
ν	Lyr	4.41	4.24	—	—	—	—	5.11	5.25	1.7	A3V
α	Mic	4.08	3.91	—	—	—	—	—	4.90	0.3	G8III
γ	Mic	4.08	3.91	—	—	—	—	—	4.67	0.3	G8III
η	Mic	3.41	2.91	—	—	—	—	—	5.53	−0.1	K3III
θ1	Mic	3.41	2.91	—	—	—	—	—	4.82	—	A2p
θ2	Mic	5.08	4.91	—	—	—	—	—	5.77	−0.6	A0III
2	Mon	—	—	—	—	—	—	5.45	5.03	—	A6m
3	Mon	—	—	—	—	—	—	5.11	4.94	−2.5	B5III
7	Mon	—	—	—	—	—	—	5.78	5.27	−2.4	B2.5V
8	Mon	—	—	—	—	—	—	4.45	4.44	0.9	A5IV
8	Mon	—	—	—	—	—	—	—	6.72	3.4	F5V
10	Mon	—	—	—	—	—	—	4.78	5.07	−2.5	B2V
12	Mon	—	—	—	—	—	—	4.78	5.84	5.9	K0V
13	Mon	—	—	—	—	—	—	4.45	4.50	−5.2	A0Ib
15	Mon	—	—	—	—	—	—	3.78	4.66	−5.2	O7
16	Mon	—	—	—	—	—	—	5.78	5.92	−2.1	B2.5V
17	Mon	—	—	—	—	—	—	4.78	4.77	−0.2	K4III
18	Mon	—	—	—	—	—	—	4.78	4.47	−0.1	K0III
19	Mon	—	—	—	—	—	—	5.78	4.99	−3.5	B1V
20	Mon	—	—	—	—	—	—	5.78	4.92	0.2	K0III
25	Mon	—	—	—	—	—	—	5.11	5.10	0.7	F6III
27	Mon	—	—	—	—	—	—	5.45	4.93	0.1	K2III
28	Mon	—	—	—	—	—	—	5.11	4.68	−0.2	K4III
α	Mon	—	—	—	—	—	—	4.11	3.93	0.2	K0III
β	Mon	—	—	—	—	—	—	4.11	3.92	—	—
γ	Mon	—	—	—	—	—	—	4.45	3.98	−0.1	K3III
δ	Mon	4.08	3.91	3.90	—	—	—	4.11	4.15	1.4	A2V
ζ	Mon	—	—	—	—	—	—	3.78	4.34	−4.0	G2Ib
12	Oph	—	—	—	—	—	—	5.78	5.76	5.5	K2V
14	Oph	—	—	—	—	—	—	5.78	5.80	1.3	F2.7III-IV
19	Oph	—	—	—	—	—	—	5.78	6.10	1.4	A3V
20	Oph	—	—	—	—	—	—	4.78	4.65	2.0	F7IV

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
21	Oph	—	—	—	—	—	—	5.78	5.51	1.4	A2Vs
23	Oph	—	—	—	—	—	—	5.78	5.25	0.1	K2III
30	Oph	—	—	—	—	—	—	4.78	4.82	−0.2	K4III
36A	Oph	4.08	4.24	4.23	—	4.84	5.42	4.78	4.55	6.6	K0V
37	Oph	—	—	—	—	—	—	5.78	5.33	−1.1	M2III
41	Oph	—	—	—	—	—	—	4.78	4.73	0.1	K2III
44B	Oph	4.08	3.58	4.23	—	4.84	4.42	4.78	4.17	2.6	A3m
45D	Oph	4.75	4.91	4.90	—	4.84	5.75	4.78	4.29	0.6	F3III
51c,e?	Oph	5.08	4.24	4.90	—	4.84	—	4.78	4.81	0.4	B9.5V
58	Oph	—	—	—	—	—	—	4.78	4.87	3.5	F6V
61	Oph	—	—	—	—	—	—	5.78	6.17	0.5	A1IV-V
66n	Oph	4.08	3.91	3.90	—	5.84	4.08	4.78	4.64	−2.8	B2Ve
67	Oph	4.08	3.91	—	—	—	—	—	3.97	−5.7	B5Ib
68k	Oph	4.08	3.91	3.90	—	—	3.75	4.11	4.45	1.1	A2Vn
70p	Oph	4.08	3.91	3.90	—	—	3.75	4.11	4.03	5.5	K0V
72s	Oph	4.08	3.91	3.90	4.14	—	—	3.11	3.70	0.7	A4IVs
73	Oph	—	—	—	—	—	—	5.78	5.73	3.0	F2V
74r	Oph	—	—	—	—	—	5.75	4.78	4.86	0.3	G8III
α	Oph	2.75	3.24	2.90	2.81	1.84	1.75	1.78	2.10	0.8	A5III
β	Oph	3.75	3.24	3.23	2.81	2.84	2.75	2.78	2.77	0.1	K2III
γ	Oph	4.08	3.91	3.90	3.14	2.84	2.75	3.45	3.75	—	A0V
δ	Oph	3.08	—	2.90	2.81	2.84	2.75	2.78	2.74	−0.8	M1III
ε	Oph	3.08	3.24	2.90	3.14	2.84	3.08	3.11	3.24	0.3	G8III
ζ	Oph	3.08	2.91	2.90	2.81	2.84	2.75	2.45	2.60	−4.4	O9.5V
η	Oph	3.08	2.91	2.90	2.81	2.84	2.75	2.11	2.43	0.8	A2V
θ	Oph	3.75	3.58	5.23	—	2.84	3.42	2.78	3.27	−3.3	B2IV
ι	Oph	4.08	3.91	3.90	4.14	3.84	3.75	4.11	4.38	−0.5	B8V
κ	Oph	4.08	3.58	3.57	3.81	3.84	3.75	3.11	3.20	—	K2IIIvar
λ	Oph	4.08	3.91	3.90	3.81	3.84	3.75	3.45	3.82	1.1	A2V
μ	Oph	4.08	4.58	4.57	—	3.84	3.75	4.45	4.63	−2.3	B8II-III(p)Mn
ν	Oph	4.41	3.58	3.57	3.81	3.84	3.75	3.45	3.34	0.2	K0III-IV
ξ	Oph	3.75	4.24	4.23	—	—	—	—	4.39	3.2	F1III-IV
o	Oph	—	—	3.90	—	3.84	3.75	3.78	4.98	—	—
ρ	Oph	4.08	4.91	4.90	—	3.84	3.75	4.78	4.53	—	—
σ	Oph	—	—	—	—	4.84	4.75	—	4.34	—	K3IIvar
τ	Oph	4.08	4.91	4.90	4.81	4.84	4.75	4.78	4.78	—	—

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
υ	Oph	5.08	4.91	4.90	—	4.84	4.75	4.78	4.63	—	A3m
ϕ	Oph	4.75	4.91	4.90	—	4.84	3.75	4.78	4.28	0.3	G8III
χ	Oph	5.08	4.91	4.90	—	4.84	5.75	5.78	4.42	−3.3	B2IV:p
ψ	Oph	4.75	4.91	4.90	—	4.84	4.75	5.78	4.49	0.2	K0III
	Oph	5.08	4.91	4.90	—	4.84	4.75	5.78	4.45	—	A7p
6g	Ori	—	—	—	5.81	5.84	5.75	—	5.19	1.7	A3V
11y1	Ori	4.08	3.91	3.90	—	—	4.75	4.78	4.68	0.6	A0pSi
14i	Ori	—	—	—	—	5.84	4.75	5.78	5.34	—	Am
15y2	Ori	4.08	3.91	3.90	—	—	4.75	5.11	4.82	1.9	F2IV
16h	Ori	—	—	—	—	5.84	5.75	5.78	5.43	—	A2m
18	Ori	—	—	—	—	—	—	5.78	5.50	0.6	A0V
21	Ori	—	—	—	—	—	—	5.45	5.30	—	F5IIvar
22o	Ori	—	—	—	—	5.84	—	4.78	4.72	−3.0	B2IV-V
23m	Ori	—	—	—	5.81	5.84	4.75	5.11	5.00	−3.5	B1V
25	Ori	—	—	—	—	—	—	4.78	4.94	−3.5	B1V:pe
27p	Ori	—	—	—	—	5.84	—	5.78	5.08	0.2	K0III
29e	Ori	4.08	3.91	3.90	4.48	4.84	4.75	4.45	4.14	0.3	G8III
31	Ori	—	—	—	—	—	—	4.78	4.71	−0.7	K5III
32A	Ori	4.41	4.24	4.23	4.81	4.84	4.75	5.11	4.20	−1.1	B5V
33n1	Ori	6.08	5.91	5.90	—	—	—	—	5.46	−3.0	B1.5V
35	Ori	—	—	—	—	—	—	5.78	5.63	−1.7	B3V
38n2	Ori	6.08	5.91	5.90	6.14	—	—	5.78	5.36	1.4	A2V
42c1	Ori	—	—	—	4.81	—	4.75	—	4.59	−3.9	B2III
45c2	Ori	—	—	—	—	—	4.75	—	5.30	0.6	F0III
49d	Ori	4.08	4.24	4.23	4.81	4.84	4.75	4.78	4.80	1.6	A4V
51b	Ori	—	—	—	—	4.84	4.75	5.45	4.91	0.1	K1III
52	Ori	—	—	—	—	—	—	5.45	5.27	1.8	A5V
55	Ori	—	—	—	—	—	—	5.45	5.35	−2.7	B2IV-V
56	Ori	—	—	—	—	—	—	5.45	4.78	—	K2IIvar
57	Ori	—	—	—	—	—	—	5.78	5.92	−2.8	B2V
59	Ori	—	—	—	—	—	—	5.78	5.89	—	δDel
60	Ori	—	—	—	—	—	—	5.45	5.22	0.9	A1Vs
63	Ori	—	—	—	—	—	—	5.78	5.67	0.3	G7III:
64	Ori	—	—	—	—	—	—	5.78	5.14	−0.5	B8V
66	Ori	—	—	—	—	—	—	5.78	5.63	0.4	G4III
68	Ori	—	—	—	—	—	—	5.78	5.77	0.4	B9.5V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
69f1	Ori	6.08	5.91	5.90	—	—	5.75	5.45	4.98	−1.4	B5Vn
71	Ori	—	—	—	—	—	—	5.45	5.20	3.7	F6V
72f2	Ori	6.08	4.91	4.90	5.81	—	5.75	5.45	5.34	−0.6	B7V
73k1	Ori	—	—	—	—	—	5.75	5.78	5.33	−1.9	B9II-III
74k2	Ori	6.08	5.91	5.90	5.81	5.84	5.75	5.11	5.04	3.2	F5IV-V
75l	Ori	—	—	—	—	5.84	5.75	5.78	5.39	1.4	A2V
γ	Ori	2.08	1.91	1.90	2.14	1.84	1.75	1.78	1.64	−3.6	B2III
δ	Ori	2.08	1.91	1.90	1.81	1.84	1.75	1.78	2.22	—	—
ε	Ori	2.08	1.91	1.90	1.81	1.84	1.75	1.78	1.70	−6.5	B0Ia
ζ	Ori	2.08	1.91	1.90	2.14	1.84	1.75	1.78	1.6	—	—
η	Ori	3.08	3.24	3.23	2.81	2.84	2.75	3.11	3.35	—	B1V+B2
θ1	Ori	—	—	—	—	—	5.75	—	4.66	—	—
θ2	Ori	—	—	—	3.14	2.84	3.75	—	6.39	−4.7	O9.5Vpe
ι	Ori	3.08	3.24	3.23	2.81	2.84	3.08	2.78	2.77	−6.3	O9III
κ	Ori	2.75	2.58	2.57	2.81	2.84	2.75	2.45	2.06	—	B0.5Iavar
λ	Ori	—	—	—	4.14	3.84	3.75	3.11	3.18	—	—
μ	Ori	4.08	3.91	3.90	3.81	3.84	3.75	4.45	4.12	—	Am
ν	Ori	4.08	4.91	4.90	4.14	3.84	4.08	4.45	4.42	−2.6	B3IV
ξ	Ori	4.08	5.91	4.90	3.81	3.84	4.08	4.45	4.47	−2.6	B3IV
o1	Ori	—	—	—	4.14	—	4.08	5.11	4.74	—	M3Svar
o2	Ori	4.08	3.91	3.90	4.14	—	4.08	4.78	4.07	0.1	K2III
π1	Ori	4.08	3.91	3.90	3.81	—	3.75	4.78	4.65	0.6	A0V
π2	Ori	4.08	3.91	3.90	3.81	—	5.75	4.45	4.37	0.9	A1Vn
π3	Ori	3.08	3.24	3.23	3.81	—	—	3.78	3.19	3.7	F6V
π4	Ori	3.08	3.24	3.23	3.81	—	—	4.11	3.70	−3.9	B2III
π5	Ori	3.08	3.24	3.23	—	—	3.75	3.78	3.72	−3.9	B2III
π6	Ori	3.08	2.91	3.90	3.81	—	—	4.45	4.47	—	K2IIvar
ρ	Ori	—	—	—	—	3.84	—	4.78	4.45	−0.1	K0.5III
σ	Ori	—	—	—	3.81	3.84	3.75	3.45	3.80	−4.7	O9.5V
τ	Ori	3.75	3.58	3.57	3.81	3.84	3.75	3.78	3.59	−2.5	B5III
υ	Ori	4.08	4.24	4.23	3.81	3.84	3.75	4.45	4.62	−4.1	B0V
ϕ1	Ori	—	—	—	4.81	—	4.75	4.78	4.41	−4.9	B0IV
ϕ2	Ori	—	—	—	4.81	4.84	4.75	4.45	4.09	1.7	G8III-IV
χ1	Ori	5.08	4.91	4.90	4.81	4.84	4.75	4.45	4.41	4.4	G0V
χ2	Ori	5.08	5.24	5.23	—	—	4.75	4.78	4.60	—	B2Iavar
ψ	Ori	5.08	4.91	—	—	4.84	4.75	4.78	4.59	−3.3	B2IV

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
ω	Ori	4.08	3.91	3.90	—	4.84	4.75	4.78	4.57	−2.9	B3IIIe
1e	Peg	—	—	—	—	—	3.75	4.11	4.07	−0.2	K1III
2f	Peg	—	—	—	—	—	4.08	4.78	4.57	−0.8	M1III
3	Peg	—	—	—	—	—	—	5.78	6.18	1.1	A2V
4	Peg	—	—	—	—	—	—	5.45	5.70	2.1	A9IV-Vn
7	Peg	—	—	—	—	—	—	5.45	5.30	−1.1	M2III
9g	Peg	—	—	—	—	—	4.08	4.78	4.34	−3.9	G5Ib
11	Peg	—	—	—	—	—	—	5.45	5.64	1.2	A1V
12	Peg	—	—	—	—	—	—	5.45	5.29	−3.6	K0Ib
13	Peg	—	—	—	—	—	—	5.78	5.29	1.3	F2III-IV
14	Peg	—	—	—	—	—	—	4.78	5.04	0.9	A1Vs
15	Peg	—	—	—	—	—	—	5.45	5.50	—	F6IVvw
16	Peg	—	—	—	—	—	—	5.11	5.08	−2.0	B3V
17	Peg	—	—	—	—	—	—	5.45	5.60	1.4	A2Vnn
18	Peg	—	—	—	—	—	—	5.78	6.00	−2.9	B3III
19	Peg	—	—	—	—	—	—	5.78	5.65	−0.4	K5III
20	Peg	—	—	—	—	—	—	5.45	5.60	0.7	F4III
21	Peg	—	—	—	—	—	—	5.45	5.80	0.4	B9.5V
23	Peg	—	—	—	—	—	—	5.45	5.63	−0.1	B9Vn
30	Peg	—	—	—	—	—	—	5.11	5.37	−1.6	B5IV
31	Peg	—	—	—	—	—	—	4.45	5.04	−2.7	B2IV-V
32	Peg	—	—	—	—	—	—	4.78	4.81	−0.8	B9III
34	Peg	—	—	—	—	—	—	5.78	5.75	3.8	F7V
35	Peg	—	—	—	—	—	—	5.45	4.79	0.2	K0III
36	Peg	—	—	—	—	—	—	5.78	5.58	−0.4	K5III
37	Peg	—	—	—	—	—	—	5.45	5.48	1.8	F5IVs
38	Peg	—	—	—	—	—	—	5.45	5.63	0.4	B9.5V
39	Peg	—	—	—	—	—	—	5.78	6.24	2.8	F1V
40	Peg	—	—	—	—	—	—	5.78	5.82	−1.9	G8II
41	Peg	—	—	—	—	—	—	5.78	6.21	1.4	A2V
45	Peg	—	—	—	—	—	—	5.78	6.25	0.4	G6III:
51	Peg	—	—	—	—	—	—	5.45	5.49	4.8	G5V
52	Peg	—	—	—	—	—	—	5.78	5.75	2.4	A7V
55l	Peg	—	—	—	—	—	4.75	5.78	4.52	−1.1	M2III
56	Peg	—	—	—	—	—	—	5.78	4.74	−2.3	K0IIp
57m	Peg	—	—	—	—	—	5.75	6.11	5.12	−1.0	M4III+A2V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
58n	Peg	—	—	—	—	—	5.75	5.11	5.40	−0.8	B9III
59p	Peg	—	—	—	—	—	5.42	4.78	5.10	2.1	A5Vn
60	Peg	—	—	—	—	—	—	5.78	6.17	1.7	G8III-IV
63	Peg	—	—	—	—	—	—	5.78	5.59	−0.7	M0III
64	Peg	—	—	—	—	—	—	5.78	5.36	−2.2	B6III
65	Peg	—	—	—	—	—	—	5.78	6.24	0.1	B9.5V
66	Peg	—	—	—	—	—	—	5.45	5.08	−0.1	K3III
67	Peg	—	—	—	—	—	—	5.78	5.57	−0.8	B9III
69	Peg	—	—	—	—	—	—	5.78	5.98	0.9	A0pHgMn
70q	Peg	—	—	—	—	—	5.08	4.78	4.55	0.3	G8III
71	Peg	—	—	—	—	—	—	5.78	5.32	−0.7	M5III
72	Peg	—	—	—	—	—	—	5.78	4.98	−0.5	K4III
73	Peg	—	—	—	—	—	—	5.78	5.63	0.2	K0III:
74	Peg	—	—	—	—	—	—	5.78	6.26	0.9	A1V
75s	Peg	—	—	—	—	—	5.75	5.45	5.40	0.9	A1Vn
77	Peg	—	—	—	—	—	—	5.45	6.29	—	K0
78	Peg	—	—	—	—	—	—	4.78	4.93	−0.1	K0III
79	Peg	—	—	—	—	—	—	5.78	5.90	—	A2m
82	Peg	—	—	—	—	—	—	5.45	5.30	1.9	A4Vn
85	Peg	—	—	—	—	—	—	5.78	5.75	5.4	G3V
86	Peg	—	—	—	—	—	—	5.78	5.51	0.4	G5III
87	Peg	—	—	—	—	—	—	5.78	5.53	0.3	G9III
α	Peg	2.41	2.24	2.23	1.81	1.84	1.75	1.78	2.49	−1.0	B9.5III
β	Peg	2.41	2.24	2.23	1.81	1.84	1.75	2.11	2.42	—	M2II-IIIvar
γ	Peg	2.41	2.24	2.23	1.81	1.84	1.75	2.45	2.83	−3.3	B2IV
ε	Peg	2.75	2.91	2.90	2.81	2.84	2.75	2.11	2.39	—	K2Ibvar
ζ	Peg	3.08	3.24	3.23	2.81	2.84	2.75	3.11	3.40	0.0	B8.5V
η	Peg	3.08	2.91	2.90	2.81	2.84	2.75	2.78	3.00	−1.9	G8II+F0V
θ	Peg	3.08	3.24	3.23	3.48	3.84	3.75	3.11	3.50	1.6	A2V
ι	Peg	3.75	3.91	3.90	3.81	3.84	3.75	3.78	3.76	3.1	F5V
κ	Peg	3.75	3.91	3.90	3.81	3.84	3.75	3.78	4.13	1.8	F5IV
λ	Peg	4.08	3.58	3.57	4.14	3.84	3.75	3.78	3.95	−0.8	G8II-III
μ	Peg	4.08	3.58	3.57	4.14	3.84	3.75	3.78	3.48	0.3	G8III
ν	Peg	4.08	5.24	5.23	4.81	4.84	4.75	4.78	4.84	−0.5	K4III
ξ	Peg	4.08	4.24	4.23	4.81	4.84	4.75	4.45	4.20	2.6	F7V
o	Peg	5.08	4.91	4.90	4.81	4.84	4.75	4.78	4.79	0.3	A1IV

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
π	Peg	3.75	3.91	3.90	3.81	4.84	4.08	3.78	4.29	0.7	F5III
ρ	Peg	5.08	5.24	5.23	5.81	5.84	5.75	4.78	4.90	1.2	A1V
σ	Peg	5.08	5.24	5.23	6.14	5.84	5.75	4.78	5.16	2.0	F7IV
τ	Peg	4.08	3.91	3.90	5.81	5.84	5.75	4.45	4.60	2.1	A5V
υ	Peg	4.08	3.91	3.90	5.81	5.84	5.75	4.45	4.40	2.4	F8IV
ϕ	Peg	—	—	—	—	5.84	5.75	5.45	5.08	−1.1	M2III
χ	Peg	—	—	—	—	5.84	5.75	4.78	4.80	−1.1	M2III
ψ	Peg	—	—	—	—	5.84	5.75	4.78	4.66	−1.1	M3III
1	Per	—	—	—	—	—	—	5.78	5.50	−3.3	B1.5V
2	Per	—	—	—	—	—	—	5.78	5.79	—	B9pHgMn
3	Per	—	—	—	—	—	—	5.78	5.69	3.2	K0IV
4	Per	—	—	—	—	5.84	—	5.11	5.00	−1.5	B8III
9i	Per	—	—	—	5.81	5.84	5.75	5.45	5.20	−7.5	A2Ia
12q	Per	—	—	—	—	—	5.75	4.78	4.90	3.9	F9V
14	Per	—	—	—	—	—	—	5.78	5.43	−4.1	G0Ib
16p1	Per	—	4.91	4.90	4.14	5.84	3.75	4.45	4.20	0.6	F2III
17r	Per	—	—	—	—	—	5.08	4.78	4.53	−0.4	K5III
20p2	Per	—	—	—	—	—	5.75	5.78	5.35	—	F4Vvar
21	Per	—	—	—	—	—	—	4.78	5.11	—	B9pSi
24s	Per	—	—	—	—	—	5.75	4.78	4.93	0.1	K2III
29	Per	—	—	—	—	—	—	4.78	5.15	−2.0	B3V
30	Per	—	—	—	—	—	—	5.78	5.46	−0.5	B8V
31	Per	—	—	—	—	—	—	4.78	5.02	−1.1	B5V
32l	Per	—	—	—	—	5.84	5.75	4.78	5.00	1.7	A3V
36	Per	—	—	—	—	—	—	4.78	5.30	—	F4IIIvar
40o	Per	—	—	—	—	5.84	—	4.78	4.97	−4.1	B0.5V
42n	Per	—	—	—	—	5.84	5.75	5.45	5.11	1.4	A3V
43A	Per	—	—	—	5.14	4.84	4.75	5.11	5.30	1.8	F5IV
48c	Per	4.08	3.91	3.90	4.48	4.84	4.75	3.78	4.04	−1.7	B3Ve
50	Per	—	—	—	—	—	—	5.78	5.50	3.8	F7V
52f	Per	5.08	5.24	5.23	—	4.84	4.75	4.78	4.71	−2.0	G5II+A2V
53d	Per	5.08	4.91	4.90	5.48	4.84	5.75	4.78	4.84	−2.0	B4IV
54	Per	—	—	—	—	—	—	5.78	4.93	0.3	G8III
55	Per	—	—	—	—	—	—	5.78	5.73	−0.2	B8V
57m	Per	—	—	—	—	5.84	5.75	5.78	6.09	2.6	F0V
58e	Per	5.08	4.91	4.90	4.48	4.84	4.75	4.78	4.25	−1.2	K0II-III+B9V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
59	Per	—	—	—	—	—	—	5.78	5.29	1.2	A1Vn
α	Per	2.08	1.91	1.90	1.81	1.84	2.08	1.78	1.79	−4.5	F5Ib
γ	Per	3.41	3.24	3.23	2.81	2.84	2.75	2.78	2.90	0.0	G5III+A2V
δ	Per	3.08	2.91	2.90	3.14	2.84	2.75	2.78	2.99	−2.5	B5III
ε	Per	3.08	2.91	2.90	2.81	2.84	2.75	3.11	2.88	−4.1	B0.5V
ζ	Per	2.75	3.24	3.23	2.81	2.84	2.75	2.78	2.93	−6.5	B1Iab:
η	Per	4.08	3.91	3.90	3.81	3.84	—	3.45	3.79	−3.9	K3Ibcomp
θ	Per	4.08	3.58	4.23	3.81	3.84	3.75	3.78	4.12	3.6	F7V
ι	Per	4.08	3.91	3.90	3.81	3.84	—	3.78	4.05	3.7	G0V
κ	Per	4.08	3.91	3.90	4.14	3.84	4.42	4.11	3.80	−0.1	K0III
λ	Per	4.08	3.91	3.90	—	3.84	3.75	4.11	4.29	0.0	A0IVn
μ	Per	4.08	3.91	3.90	3.81	3.84	3.75	4.11	4.18	—	G0Ib+B9/A0
ν	Per	3.75	3.91	3.90	3.81	3.84	3.75	3.78	3.80	—	F5IIvar
ξ	Per	4.08	3.91	3.90	4.81	3.84	4.75	3.78	4.04	−5.8	O7.5I
o	Per	3.41	3.24	3.23	—	—	—	3.78	3.82	−4.7	B1III
π	Per	4.08	3.91	3.90	3.81	3.84	3.75	4.78	4.70	1.1	A2Vn
ρ	Per	4.08	3.58	3.57	3.81	3.84	3.75	3.78	3.39	—	M3IIIvar
σ	Per	4.08	3.91	3.90	4.81	3.84	4.75	—	4.36	−0.1	K3III
τ	Per	4.08	4.91	4.90	4.81	4.84	4.75	3.78	3.95	0.2	G5III+A4V
ϕ	Per	4.41	3.91	—	4.14	4.84	—	3.78	4.09	−2.8	B2Vpe
ψ	Per	4.08	3.91	3.90	4.48	4.84	4.75	4.78	4.23	−1.1	B5Ve
	Per	4.08	4.24	4.23	4.81	4.84	4.75	4.78	4.63	0.1	K1III
8	PsA	—	—	—	—	—	—	5.45	5.73	1.5	A7/A8IV
α(Nr.670)	PsA	1.08	0.91	0.90	0.81	0.84	0.75	1.11	1.16	2.0	A3V
β	PsA	4.08	3.91	3.90	—	3.84	2.75	3.78	4.29	1.2	A1V
γ	PsA	4.08	3.91	3.90	—	3.84	4.75	4.45	4.50	−0.6	A0III
δ	PsA	4.08	3.91	3.90	—	3.84	4.75	4.45	4.21	0.3	G8III
ε	PsA	3.75	3.91	3.90	—	3.84	3.08	3.78	4.20	−0.2	B8V
ζ	PsA	5.08	6.24	5.23	—	3.84	—	5.11	6.43	0.1	K1III
η	PsA	4.08	4.91	4.90	—	3.84	4.75	5.11	5.42	—	B8/9V+B8/9
θ	PsA	4.08	4.58	5.23	—	3.84	3.75	5.11	5.01	1.2	A1V
ι	PsA	4.08	3.91	3.90	—	3.84	3.75	4.78	4.30	0.1	B9.5V
λ	PsA	4.08	4.91	4.90	—	4.84	4.08	4.78	5.43	−0.6	B7V
μ	PsA	5.08	4.91	4.90	—	4.84	3.75	4.45	4.50	1.4	A2V
2	Psc	—	—	—	—	—	—	5.78	5.43	0.1	K1III:
3	Psc	—	—	—	—	—	—	5.78	6.21	0.4	G4III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
5A	Psc	—	—	—	—	5.84	5.75	5.78	5.40	1.7	G8III-IV
7b	Psc	4.08	4.24	4.23	5.81	5.84	5.08	5.78	5.05	—	K2
14	Psc	—	—	—	—	—	—	5.78	5.87	—	A2m
16	Psc	—	—	—	—	—	—	5.78	5.68	—	F6Vbvw
19	Psc	—	—	—	—	—	—	5.78	5.05	—	C5II
20	Psc	—	—	—	—	—	—	5.78	5.49	0.3	G8III
21	Psc	—	—	—	—	—	—	5.78	5.70	1.1	A5m
25	Psc	—	—	—	—	—	—	5.78	6.32	0.9	A1V
27	Psc	4.08	3.91	3.90	—	—	—	5.11	4.86	−0.1	G9III
29	Psc	4.08	3.91	3.90	—	—	—	5.11	5.10	−1.3	B7III-IV
30	Psc	4.08	3.91	3.90	—	—	—	4.78	4.41	−1.1	M3III
32c	Psc	—	—	—	—	5.84	—	5.78	5.60	2.6	F0V
33	Psc	4.08	3.91	3.90	—	—	—	4.78	4.61	0.4	K0IIIb
34	Psc	—	—	—	—	—	—	5.78	5.53	0.2	B9V
35	Psc	—	—	—	—	—	—	5.78	5.79	—	—
36	Psc	—	—	—	—	—	—	5.78	6.11	−0.8	G8II-III
41d	Psc	6.08	5.91	5.90	6.14	5.84	5.75	5.45	5.37	−0.1	K3III
47	Psc	—	—	—	—	—	—	5.45	5.06	—	M3IIIvar
48	Psc	—	—	—	—	—	—	5.78	6.06	−0.7	K5III
51	Psc	6.08	5.91	5.90	—	—	—	5.78	5.67	0.4	B9.5V
52	Psc	—	—	—	—	—	—	5.78	5.38	0.2	K0III
53	Psc	—	—	—	—	—	—	5.78	5.89	−2.9	B2.5IV
55	Psc	—	—	—	—	—	—	5.45	5.40	—	F3Vcomp
57	Psc	—	—	—	—	—	—	5.45	6.15	4.4	G0V
58	Psc	—	—	—	—	—	—	4.78	5.50	−1.9	G8II
59	Psc	—	—	—	—	—	—	5.78	6.13	2.6	F0Vn
64	Psc	—	—	—	—	—	—	5.45	5.07	3.4	F8V
65i	Psc	6.08	5.91	6.23	5.81	—	—	5.78	6.3	—	—
66	Psc	—	—	—	—	—	—	5.78	5.74	0.9	A1Vn
67k	Psc	6.08	5.91	6.23	5.81	5.84	5.75	5.78	6.00	1.2	A5IV
68h	Psc	6.08	5.91	6.23	6.14	5.84	5.75	5.78	5.42	0.4	G6III
72	Psc	—	—	—	—	—	—	5.78	5.68	−0.9	F4II-III
80e	Psc	6.08	5.91	5.90	5.81	5.84	4.75	5.45	5.50	1.2	F0III-IV
82g	Psc	5.08	4.91	4.90	5.48	5.84	5.75	4.78	5.16	2.6	F0V
87	Psc	—	—	—	—	—	—	5.78	5.98	−1.2	B8III
88	Psc	—	—	—	—	—	—	5.78	6.03	0.4	G6III:

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
89f	Psc	6.08	4.91	4.90	5.81	5.84	5.75	5.11	5.16	1.4	A3V
91l	Psc	—	—	—	—	5.84	5.75	4.78	5.23	−0.4	K5III
105	Psc	—	—	—	—	—	—	5.78	5.97	0.1	K2III
107	Psc	—	—	—	—	—	—	5.11	5.20	5.8	K1V
α	Psc	3.08	3.24	3.23	2.81	2.84	2.75	3.11	3.39	—	—
β	Psc	4.08	3.91	3.90	4.48	3.84	4.75	4.45	4.53	−0.9	B6Ve
γ	Psc	4.08	4.24	4.23	3.81	3.84	3.75	3.78	3.69	0.3	G7III
δ	Psc	4.08	3.91	3.90	3.81	3.84	3.75	4.11	4.43	−0.4	K5III
ε	Psc	4.08	3.91	3.90	3.81	3.84	3.75	3.78	4.28	0.2	K0III
ζ	Psc	4.08	5.91	3.90	3.81	3.84	3.75	4.45	4.9	—	—
η	Psc	3.08	4.91	3.23	4.14	3.84	3.75	3.45	3.61	0.3	G8III
θ	Psc	4.08	3.91	3.90	4.81	3.84	4.75	4.11	4.28	0.1	K1III
ι	Psc	4.08	3.91	3.90	4.81	—	5.75	4.11	4.13	3.3	F7V
κ	Psc	4.08	3.91	3.90	5.14	—	—	4.45	4.94	—	A0pCr(SiSr)
λ	Psc	4.08	3.91	3.90	4.81	4.84	4.75	4.78	4.50	2.1	A7V
μ	Psc	4.08	4.24	4.23	4.81	4.84	4.75	4.78	4.84	−0.2	K4III
ν	Psc	4.08	3.91	3.90	4.48	4.84	4.75	4.45	4.44	−0.1	K3III
ξ	Psc	4.08	3.91	3.90	4.48	4.84	5.75	3.78	4.62	−0.1	K0III
o	Psc	4.08	3.91	3.90	—	4.84	4.75	3.78	4.26	0.2	K0III
π	Psc	5.08	5.24	5.23	—	4.84	4.75	5.78	5.60	2.6	F0V
ρ	Psc	4.08	4.91	4.90	4.81	4.84	4.75	4.78	5.38	—	F2V:var
σ	Psc	—	—	—	—	4.84	—	4.78	5.51	0.1	B9.5V
τ	Psc	5.08	4.91	4.57	4.81	4.84	4.75	3.78	4.51	1.4	K0III-IV
υ	Psc	4.08	3.91	3.90	4.81	4.84	4.75	3.78	4.76	1.4	A3V
ϕ	Psc	4.08	3.91	3.90	4.81	4.84	4.75	4.78	4.66	−0.1	K0III
χ	Psc	4.08	3.91	3.90	4.81	4.84	4.75	4.45	4.66	0.2	K0III
ψ1	Psc	4.08	3.91	3.90	4.81	—	4.75	4.45	4.69	—	—
ψ2	Psc	4.08	3.91	3.90	5.81	—	5.75	4.45	5.60	1.7	A3V
ψ3	Psc	4.08	3.91	3.90	5.48	4.84	5.75	5.45	5.55	0.6	G0III
ω	Psc	4.08	5.91	3.90	4.48	4.84	4.75	3.78	4.00	1.7	F4IV
3	Pup	4.08	3.91	3.90	—	—	—	—	3.96	−7.0	A2Iab
11e	Pup	5.08	4.91	—	—	—	—	—	4.20	−2.0	F7II
ζ	Pup	2.08	1.91	1.90	—	—	—	—	2.20	—	O5Iaf
ν	Pup	2.75	2.58	3.23	—	—	—	—	3.20	−1.5	B8III
ξ	Pup	4.08	3.58	3.57	—	—	—	—	3.35	−4.3	G3Ib
o	Pup	4.08	4.91	2.90	—	—	—	—	4.50	−4.1	B0V:pe:

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
π	Pup	3.08	2.91	2.90	—	—	—	—	2.70	−0.5	K4III
ρ	Pup	3.08	2.91	2.90	—	—	—	—	2.81	—	δDel
σ	Pup	4.08	3.58	3.57	—	—	—	—	3.25	−0.7	K5III
τ	Pup	2.75	3.24	3.23	—	—	—	—	2.93	−0.1	K0III
α	Pyx	3.08	3.91	3.90	—	—	—	—	3.70	−4.0	B1.5III
β	Pyx	3.08	3.91	3.90	—	—	—	—	3.97	−1.0	G5II/III
γ	Pyx	4.08	4.24	4.23	—	—	—	—	4.01	−0.1	K3III
δ	Pyx	4.08	3.91	4.23	—	—	—	—	4.89	0.9	A3IV
1b	Sco	—	—	—	—	4.84	—	4.78	4.70	−1.7	B3V
2A	Sco	—	—	—	—	4.84	—	4.78	4.59	−2.1	B2.5Vn
β	Sco	3.08	2.91	2.90	2.14	1.84	1.75	1.78	2.50	—	—
δ	Sco	3.08	2.91	—	2.48	2.84	2.75	2.11	2.30	−4.5	B0.5IV
ε	Sco	3.08	2.91	2.90	—	2.84	2.75	2.78	2.29	0.7	K2IIIb
ζ1	Sco	4.08	3.91	3.90	—	—	—	—	4.73	−6.6	B1Iae
ζ2	Sco	4.08	3.91	3.90	—	—	—	—	3.62	−0.2	K4III
η	Sco	3.08	3.24	3.23	—	2.84	—	—	3.33	2.1	F3III-IVp
θ	Sco	3.08	2.91	2.90	—	2.84	—	—	1.90	−2.0	F1II
ι1	Sco	3.08	3.24	—	—	—	—	—	3.00	−8.6	F3Ia
κ	Sco	3.08	2.91	2.90	—	2.84	—	—	2.40	−4.3	B1.5III
λ	Sco	3.08	2.91	2.90	—	2.84	—	2.78	1.60	—	B1.5IV+B
ν	Sco	4.08	3.91	3.90	4.14	3.84	3.75	3.78	3.89	—	—
ξ	Sco	4.41	4.24	—	—	3.84	—	4.11	4.13	—	—
o	Sco	—	—	—	—	3.84	—	—	4.55	−2.1	A5II
π	Sco	3.08	2.91	2.90	2.48	3.84	2.75	2.78	2.89	−3.9	B1V+B2V
ρ	Sco	3.08	3.24	3.23	4.14	3.84	3.75	4.45	3.90	−2.7	B2IV/V
σ	Sco	3.08	3.24	3.23	3.81	3.84	4.75	3.11	2.88	−4.9	B2III+O9.5V
τ	Sco	3.08	2.91	2.90	3.81	3.84	3.75	3.11	2.82	−4.1	B0V
υ	Sco	4.08	3.24	3.23	—	3.84	3.75	3.78	2.70	−3.3	B2IV
χ	Sco	—	—	—	—	—	4.75	5.78	5.22	−0.1	K3III
ψ	Sco	—	—	—	—	—	—	4.78	4.94	0.9	A3IV
1	Sco	—	—	—	—	—	4.75	—	3.96	−3.5	B1V
ω2	Sco	—	—	—	—	—	4.75	—	4.32	−0.7	G3II-III
3	Ser	—	—	—	—	—	—	5.78	5.33	0.2	K0III
4	Ser	—	—	—	—	—	—	5.78	5.70	1.9	A4V
5	Ser	—	—	—	—	—	—	4.78	5.10	1.5	F8III-IV
6	Ser	—	—	—	—	—	—	5.78	5.35	−0.1	K3III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
10	Ser	—	—	—	—	—	—	5.78	5.17	1.2	A8IV
11A1	Ser	—	—	—	—	—	5.75	5.78	5.51	0.2	K0III
16	Ser	—	—	—	—	—	—	5.78	5.23	—	K0p
25A2	Ser	—	—	—	—	5.84	5.75	5.78	5.39	−1.5	B8III
36b	Ser	—	—	—	—	5.84	5.75	4.78	5.10	1.7	A3Vn
45	Ser	—	—	—	—	—	—	5.78	5.63	2.1	A7V
47	Ser	—	—	—	—	—	—	5.78	5.73	−1.1	M3III
59d	Ser	—	—	—	—	5.84	5.75	5.78	5.21	0.4	G0III+A6V
60c	Ser	—	—	—	—	5.84	5.75	5.78	5.39	−0.1	K0III
64	Ser	—	—	—	—	—	—	5.78	5.57	−0.8	B9III(p)(Hg)
α	Ser	3.08	2.91	2.90	1.81	1.84	1.75	2.11	2.65	1.0	K2III
β	Ser	3.08	3.24	3.23	2.48	2.84	2.75	3.11	3.67	0.6	A2IV
γ	Ser	3.08	3.24	3.23	2.81	2.84	2.75	3.45	3.85	3.4	F6V
δ	Ser	3.08	3.24	3.23	2.48	2.84	2.75	3.11	3.05	—	—
ε	Ser	3.08	3.24	3.23	2.81	2.84	2.75	3.11	3.71	—	A2m
ζ	Ser	4.08	3.91	3.90	2.81	2.84	2.75	4.78	4.62	2.8	F3V
η	Ser	3.75	3.58	3.57	3.14	2.84	2.75	2.78	3.26	1.9	K0III-IV
θ	Ser	4.08	3.91	3.90	2.81	2.84	2.75	3.45	4.03	—	—
ι	Ser	4.08	3.91	3.90	4.48	3.84	4.75	4.45	4.52	0.9	A1V
κ	Ser	4.08	4.91	4.90	3.81	3.84	3.75	3.78	4.09	−0.8	M1III
λ	Ser	4.08	3.91	3.90	—	3.84	3.75	4.11	4.43	4.2	G0Vvar
μ	Ser	4.08	3.91	3.90	3.81	3.84	3.75	3.11	3.53	0.3	A0V
ν	Ser	4.08	3.91	3.90	—	3.84	3.75	4.45	4.33	1.4	A2V
ξ	Ser	3.75	3.58	3.57	—	3.84	3.75	3.45	3.50	1.4	F01V δSct
o	Ser	4.08	3.91	3.90	—	3.84	4.75	4.45	4.26	1.1	A2V
π	Ser	4.08	4.24	4.23	4.14	4.84	3.75	4.78	4.80	1.4	A3V
ρ	Ser	4.08	4.24	4.23	3.14	4.84	3.42	4.78	4.76	−0.4	K5III
σ	Ser	—	—	—	—	4.84	4.75	4.78	4.80	2.6	F0V
τ1	Ser	—	—	—	—	5.84	6.75	5.78	5.17	−0.8	M1III
τ2	Ser	—	—	—	—	—	5.75	5.78	6.22	0.2	B9V
τ3	Ser	—	—	—	—	—	5.75	5.78	6.12	0.3	G8III:
τ4	Ser	—	—	—	—	—	—	5.78	6.65	—	M5II-III
τ5	Ser	—	—	—	—	—	—	5.78	5.93	3.1	F3V
τ6	Ser	—	—	—	—	—	—	5.78	6.01	0.3	G8III
τ7	Ser	—	—	—	—	—	—	5.78	5.81	—	A2m
τ8	Ser	—	—	—	—	—	—	5.78	6.14	0.3	A0V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
υ	Ser	—	—	—	—	5.84	5.75	5.78	5.71	1.7	A3V
ϕ	Ser	—	—	—	—	5.84	—	5.78	5.54	—	K1IV
χ	Ser	—	—	—	—	5.84	5.75	5.78	5.33	—	A0pSr
ψ	Ser	—	—	—	—	5.84	5.75	5.78	5.88	4.2	G5V
	Ser	—	—	—	—	5.84	5.75	5.78	5.23	0.3	G8III
24α(15?)	Sex	—	—	3.90	—	—	—	—	4.49	−0.6	A0III
ε	Sex	3.08	3.91	—	—	—	—	—	5.24	0.6	F2III
1	Sge	—	—	—	—	—	—	5.78	5.60	1.9	A4V
2	Sge	—	—	—	—	—	—	5.78	6.25	−0.1	A2III-IV
3	Sge	—	—	—	—	—	—	5.78	6.82	—	A0
10	Sge	—	—	—	—	—	—	5.78	5.36	—	G5Ibv
11	Sge	—	—	—	—	—	—	5.78	5.33	−0.8	B9III
13	Sge	—	—	—	—	—	—	5.78	5.37	−0.9	M4III
15	Sge	—	—	—	—	—	—	5.78	5.80	4.6	G1V
18	Sge	—	—	—	—	—	—	5.78	6.13	0.1	K1III
α	Sge	5.08	4.91	4.90	4.14	3.84	3.75	4.11	4.37	−2.0	G0II
β	Sge	5.08	4.91	4.90	3.81	3.84	3.75	4.11	4.37	−1.9	G8II
γ	Sge	4.08	3.91	3.90	3.81	3.84	3.75	3.45	3.47	−0.4	K5III
δ	Sge	5.08	4.91	4.90	5.14	4.84	4.08	3.78	3.82	−2.9	M2II+A0V
ε	Sge	—	—	—	—	5.84	4.75	5.78	5.66	—	G8IIIvar
ζ	Sge	6.08	5.91	5.90	5.81	5.84	5.75	4.78	5.00	1.7	A3V
η	Sge	—	—	—	—	5.84	5.75	5.11	5.10	0.1	K2III
θ	Sge	—	—	—	—	5.84	5.75	5.78	6.48	2.1	F5IV
3p	Sgr	5.08	4.91	4.90	—	—	5.75	4.78	4.22	−2.0	F7II
4	Sgr	—	—	—	—	—	—	4.78	4.76	0.2	B9V
6	Sgr	—	—	—	—	—	—	5.78	6.28	−0.1	K3III
9	Sgr	—	—	—	—	—	—	4.45	5.97	−5.3	O5
15	Sgr	—	—	—	—	—	—	4.78	5.38	−6.5	B0Ia
21	Sgr	—	—	—	—	—	—	4.78	4.81	—	K2II+A5:
43d	Sgr	5.08	5.24	5.23	4.81	5.84	5.75	4.78	4.96	−1.9	G8II
50	Sgr	—	—	—	—	—	—	5.78	5.59	−0.1	K3III
51h1	Sgr	—	—	—	—	—	5.75	—	5.65	—	Am
52h2	Sgr	—	—	—	—	5.84	5.75	4.45	4.60	1.0	B9
53	Sgr	—	—	—	—	—	—	5.78	6.34	−0.1	B9.5V+A3IV
54 e1	Sgr	—	—	—	6.14	—	5.75	5.78	5.33	—	K2IIIcomp
55 e2	Sgr	6.08	5.91	—	—	5.84	5.75	4.78	5.06	0.3	F1III

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
56f	Sgr	—	—	5.90	—	5.84	5.75	4.78	4.86	0.1	K1III
57	Sgr	6.08	5.91	—	—	—	—	—	5.92	0.1	G5III
59b	Sgr	5.08	4.91	4.90	—	—	4.75	4.78	4.52	−0.4	K3III
60A	Sgr	5.08	4.91	4.90	—	4.84	4.75	4.78	4.83	−1.1	G8II/III
61g	Sgr	5.08	5.24	5.23	6.14	5.84	5.75	5.45	5.02	3.3	A3IV
62c	Sgr	5.08	4.91	4.90	—	4.84	5.75	4.78	4.58	−0.9	M4III
63	Sgr	—	—	—	—	—	—	5.78	5.71	1.7	A3V
α	Sgr	2.41	4.24	4.23	—	1.84	5.75	—	4.00	−0.5	B8V
γ	Sgr	3.08	3.24	3.23	3.81	2.84	—	3.11	2.99	−0.1	K0III
δ	Sgr	3.08	2.91	2.90	4.14	2.84	2.75	3.11	2.70	−0.1	K3III
ε	Sgr	3.08	2.58	2.57	—	2.84	2.75	2.45	1.80	−0.7	B9.5III
ζ	Sgr	3.08	2.91	2.90	—	2.84	2.75	3.11	2.60	0.6	A3IV
η	Sgr	3.08	3.24	3.23	—	—	—	3.78	3.11	−1.1	M2III
ι	Sgr	3.08	4.24	4.23	—	—	—	—	4.13	0.2	K0III
λ	Sgr	3.08	2.91	2.90	3.81	3.84	3.75	2.78	2.81	1.1	K0III
μ	Sgr	4.08	3.91	—	5.14	3.84	—	3.78	3.86	−7.4	B8Iap
ξ1	Sgr	—	—	—	—	—	4.75	—	5.08	−2.8	A0II
ξ2	Sgr	4.08	3.91	3.90	3.81	3.84	5.75	—	3.51	0.1	K1III
o	Sgr	4.08	3.91	3.90	6.14	3.84	3.75	3.78	3.77	0.8	G9IIIb
π	Sgr	4.08	3.91	3.57	3.81	3.84	3.75	2.78	2.89	0.6	F3III
ρ1	Sgr	—	—	—	—	3.84	4.75	—	3.93	2.1	F0IV-V
ρ2	Sgr	—	—	—	—	—	5.75	—	5.87	−0.1	G9III:
σ	Sgr	3.08	2.91	2.90	3.81	3.84	3.42	2.11	2.00	−2.1	B2.5V
τ	Sgr	3.75	4.24	3.57	—	3.84	3.75	3.45	3.32	−0.2	K1/K2III
υ	Sgr	4.08	4.24	4.23	5.81	4.84	5.75	4.45	4.61	—	Ape+O9V
ϕ	Sgr	4.08	3.58	3.57	4.14	4.84	—	3.45	3.20	−1.3	B8.5III
χ1	Sgr	5.08	5.24	—	—	—	4.75	—	5.03	2.1	Am
χ3	Sgr	—	—	—	—	—	5.75	—	5.43	−0.2	K4III
ψ	Sgr	5.08	5.24	5.23	—	4.84	4.75	5.78	4.85	0.2	G8:III+A8V
ω	Sgr	5.08	4.91	4.90	—	4.84	4.75	4.78	4.70	3.4	G5V
7	Tau	—	—	—	—	—	—	5.78	5.95	1.7	A3V
10	Tau	4.08	3.91	3.90	—	—	—	4.11	4.28	2.9	F9V
12	Tau	—	—	—	—	—	—	5.78	5.57	0.4	G6III:
13	Tau	—	—	—	—	—	—	5.78	5.69	−0.1	B9Vn
20	Tau	—	—	—	—	—	—	4.78	3.87	−1.5	B8III
31	Tau	—	—	—	—	—	—	5.78	5.67	−1.1	B5V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
32	Tau	—	—	—	—	—	—	5.78	5.70	1.9	F2IV
36	Tau	—	—	—	—	—	—	5.78	5.47	−0.4	G1III+B9V
40	Tau	—	—	—	—	—	—	5.78	5.32	−1.7	B3V
41	Tau	—	—	5.23	4.81	—	—	5.45	5.20	—	B9pSi
43	Tau	—	—	—	—	—	—	5.78	5.50	0.1	K2III
45	Tau	—	—	—	—	—	—	5.78	5.70	3.3	F4V
46	Tau	—	—	—	—	—	—	5.78	5.29	2.4	F2V+F5V
47	Tau	—	—	—	—	—	—	4.78	4.84	0.2	G5III:+A7V:
48	Tau	—	—	—	—	—	—	5.78	6.30	—	F5Vvar
53	Tau	—	—	—	—	—	—	5.78	5.35	−0.6	B9IV
56	Tau	—	—	—	—	—	—	5.78	5.38	—	A0pSi
60	Tau	—	—	—	—	—	—	5.78	5.70	—	A3m
62	Tau	—	—	—	—	—	—	5.78	6.36	−1.7	B3V
71	Tau	—	—	—	—	—	—	5.78	4.49	2.3	F0V
72	Tau	—	—	—	—	—	—	5.78	5.52	−0.6	B7V
83	Tau	—	—	—	—	—	—	5.78	5.40	2.6	F0V
105	Tau	—	—	—	—	—	—	5.78	5.92	−2.5	B2Ve
111	Tau	—	—	—	—	—	—	5.45	7.95	6.7	K2
115	Tau	—	—	—	—	—	—	5.78	5.42	−1.1	B5V
116	Tau	—	—	—	—	—	—	5.78	5.50	0.4	B9.5Vn
118	Tau	—	—	—	—	—	—	5.78	5.47	0.0	B8.5V
119	Tau	—	—	—	—	—	—	5.45	4.49	−4.2	M2Ib
121	Tau	5.08	4.91	4.90	—	—	—	5.78	5.38	−2.9	B2.5IV
122	Tau	—	—	—	—	—	—	5.78	5.50	2.6	F0V
125	Tau	5.08	4.91	4.90	—	—	—	5.78	5.17	−2.6	B3IV
126	Tau	5.08	4.91	4.90	—	—	—	4.78	4.86	—	B3IV
129	Tau	5.08	6.24	6.23	—	—	—	—	6.00	−1.2	B8IIIpHg(Mn)
130	Tau	—	—	—	—	—	—	5.78	5.49	0.6	F0III
132	Tau	5.08	4.91	4.90	—	—	—	5.11	4.86	—	G8IIIvar
133	Tau	—	—	—	—	—	—	5.78	5.29	−2.7	B2IV-V
134	Tau	—	—	—	—	—	—	5.11	4.91	−0.3	B9IV
135	Tau	—	—	—	—	—	—	5.78	5.52	0.3	G9III:
136	Tau	5.08	4.91	4.90	—	—	—	—	4.58	0.3	A0V
137	Tau	—	—	—	—	—	—	5.78	5.59	0.8	B9pSiCr
139	Tau	5.08	4.91	4.90	—	—	—	5.11	4.83	−6.0	B1Ib
104m	Tau	5.08	4.91	4.90	—	5.84	5.75	5.11	5.01	3.8	G4V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
106l1	Tau	5.08	4.91	4.90	5.81	5.84	5.75	5.45	5.29	2.1	A5V
109n	Tau	5.08	4.91	4.90	5.81	5.84	5.75	5.78	4.94	0.3	G8III
114o	Tau	5.08	4.91	—	5.81	5.84	4.75	5.78	4.87	−2.6	B2.5IV
16g	Tau	—	—	—	—	5.84	6.75	—	5.46	−1.0	B7IV
17b	Tau	—	—	—	4.81	—	4.75	3.78	3.70	−2.2	B6III
19q	Tau	5.08	4.91	4.90	—	—	—	4.78	4.30	−1.2	B6V
23d	Tau	5.08	4.91	4.90	6.14	—	—	4.78	4.18	−1.3	B6IV
27f	Tau	5.08	4.91	4.90	4.81	—	4.75	3.78	3.63	−1.5	B8III
29u1	Tau	—	—	—	5.81	5.84	5.75	5.45	5.35	−2.0	B3V
30e	Tau	5.08	5.91	5.90	4.81	4.84	4.75	4.78	5.06	−1.7	B3V
37A1	Tau	5.08	4.91	4.90	4.81	4.84	4.75	4.45	4.36	0.2	K0III
44p	Tau	5.08	5.91	4.90	5.81	5.84	5.75	5.78	5.41	2.5	F2IV-V
4s	Tau	4.08	3.91	3.90	5.48	5.84	5.75	4.78	5.14	0.6	A0Vn
57h	Tau	—	—	—	—	5.84	6.75	5.78	5.60	2.8	F3V
5f	Tau	4.08	3.91	3.90	4.81	4.84	—	3.78	4.11	−1.2	K0II-III
66r	Tau	—	—	—	6.14	5.84	4.75	5.11	5.12	1.7	A3V
6t	Tau	—	—	—	—	5.84	5.75	5.78	5.76	−0.3	B9IV
79b	Tau	—	—	—	4.81	4.84	—	5.45	5.03	2.4	A7V
88d	Tau	4.08	3.91	3.90	4.81	4.84	4.75	4.45	4.25	—	A5m
90c1	Tau	4.08	3.91	3.90	4.81	4.84	4.75	4.45	4.30	1.9	A6V
93c2	Tau	—	—	—	—	—	5.75	5.45	5.49	−0.6	B8IV
97i	Tau	4.08	4.91	4.90	5.81	5.84	5.75	5.11	5.10	2.0	A7IV-V
98k	Tau	—	—	—	—	5.84	6.08	5.45	5.81	0.3	A0V
β	Tau	3.08	—	—	1.81	1.84	1.75	1.78	1.65	−1.6	B7III
γ	Tau	3.41	2.91	3.23	2.81	2.84	2.75	3.78	3.65	0.0	G8III
δ1	Tau	3.41	3.24	—	—	—	3.75	—	3.76	0.0	G8III
δ2	Tau	—	—	—	—	—	3.75	5.78	4.80	2.1	A7V
δ3	Tau	—	—	—	—	—	5.75	4.78	4.29	0.3	A2IV
ε	Tau	3.41	3.24	3.23	2.81	2.84	3.08	3.45	3.50	0.2	K0III
ζ	Tau	3.08	2.91	2.90	2.81	2.84	2.75	3.11	3.03	−2.9	B4IIIp
η	Tau	—	—	—	—	—	2.75	—	2.90	−1.6	B7III
θ1	Tau	3.41	3.24	—	—	—	4.75	4.11	3.80	0.0	G7III
θ2	Tau	—	—	—	—	—	4.75	4.11	3.40	0.2	A7III
ι	Tau	5.08	4.91	4.90	4.14	3.84	3.75	4.78	4.60	2.4	A7V
κ1	Tau	—	—	—	—	—	4.75	—	4.22	2.0	A7IV-V
κ2	Tau	—	—	—	—	—	4.75	—	5.28	2.4	A7V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
μ	Tau	4.08	3.91	3.90	3.81	3.84	3.75	4.11	4.27	−2.3	B3IV
ν	Tau	4.08	3.58	3.57	3.81	3.84	3.75	3.78	3.91	1.2	A1V
ξ	Tau	4.08	3.58	3.57	3.81	3.84	3.75	3.45	3.73	−0.1	B9Vn
o	Tau	4.08	3.58	3.57	3.81	3.84	—	3.45	3.60	0.0	G8III
π	Tau	—	—	—	4.81	4.84	4.75	4.78	4.69	0.3	G8III
ρ	Tau	—	—	—	4.81	4.84	4.75	4.78	4.70	2.1	A8V
$\sigma1$	Tau	—	—	—	—	—	5.75	—	5.10	—	A4m
$\sigma2$	Tau	—	—	—	—	—	5.75	—	4.70	1.8	A5Vn
τ	Tau	4.08	3.91	3.90	4.81	4.84	4.75	4.11	4.29	−2.0	B3V
υ	Tau	5.08	3.91	—	4.81	—	—	4.45	4.30	2.1	A8Vn
ϕ	Tau	5.08	4.91	4.90	5.14	4.84	4.75	5.11	4.95	0.1	K1III
χ	Tau	5.08	4.91	4.90	4.81	4.84	4.75	5.45	5.39	0.2	B9V
ψ	Tau	5.08	4.91	—	4.81	4.84	4.75	5.78	5.30	2.8	F1V
	Tau	6.08	5.91	—	5.81	—	—	5.45	4.94	—	A3m
α	Tel	4.08	3.91	—	—	—	—	—	3.50	−2.3	B3IV
6	Tri	—	—	—	—	—	—	5.45	4.72	—	—
7	Tri	—	—	—	—	—	—	4.78	5.28	0.6	A0V
10a	Tri	—	—	—	—	—	5.75	5.78	5.03	1.4	A2V
11	Tri	—	—	—	—	—	—	5.78	5.54	0.1	K1III:
12c	Tri	—	—	—	—	—	5.75	5.45	5.30	0.6	F0III
14	Tri	—	—	—	—	—	—	5.78	5.15	−0.4	K5III
15	Tri	—	—	—	—	—	—	5.45	5.35	−1.1	M3III
α	Tri	3.08	2.91	2.90	3.81	3.84	3.75	3.45	3.41	1.9	F6IV
β	Tri	3.08	2.91	2.90	3.48	3.84	3.75	2.78	3.00	0.0	A5III
γ	Tri	3.08	3.24	3.23	3.81	3.84	3.75	4.11	4.00	1.2	A1Vnn
δ	Tri	4.08	5.24	5.23	4.81	4.84	4.75	5.45	4.90	4.8	G0V
ε	Tri	—	—	—	—	5.84	5.75	5.11	5.50	1.4	A2V
2A	UMa	5.08	4.91	4.90	4.81	3.84	4.75	4.78	5.47	—	A2m
5b	UMa	—	—	—	—	3.84	5.75	4.78	5.70	0.6	F2III
6	UMa	—	—	—	—	—	—	5.78	5.58	0.0	G7III
15f	UMa	4.08	3.58	4.57	4.81	3.84	4.75	4.78	4.50	—	Am
16c	UMa	—	—	—	4.81	3.84	4.75	4.78	5.20	3.4	F6V
17	UMa	—	—	—	—	—	—	5.78	5.27	−0.4	K5III
18e	UMa	4.08	4.58	4.57	4.81	3.84	4.75	4.78	4.80	1.8	A5V
22	UMa	—	—	—	—	—	—	5.78	5.72	3.8	F7V
23h	UMa	4.08	3.91	3.90	3.81	3.84	3.75	3.11	3.60	1.7	F0IV

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
24d	UMa	5.08	4.91	4.90	4.81	3.84	4.08	4.45	4.60	1.8	G4III-IV
26	UMa	—	—	—	—	—	—	4.78	4.50	1.4	A2V
27	UMa	—	—	—	—	—	—	5.78	5.17	0.2	K0III
31	UMa	—	—	—	—	—	—	4.78	5.27	0.0	A3III
32	UMa	—	—	—	—	—	—	5.78	5.70	0.5	A8III
36	UMa	—	—	—	—	—	—	5.78	4.80	4.3	F8V
37	UMa	—	—	—	—	—	—	4.78	5.16	2.8	F1V
38	UMa	—	—	—	—	—	—	4.78	5.12	—	K2IIIvar
39	UMa	—	—	—	—	—	—	5.78	5.78	0.6	A0Vs
42	UMa	—	—	—	—	—	—	5.78	5.58	−0.2	K2III
43	UMa	—	—	—	—	—	—	5.78	5.67	0.1	K2III
44	UMa	—	—	—	—	—	—	4.78	5.10	−0.1	K3III
47	UMa	—	—	—	—	—	—	4.78	5.10	4.4	G0V
49	UMa	—	—	—	—	—	—	4.78	5.08	0.7	Am
51	UMa	—	—	—	—	—	—	5.78	6.00	0.5	A3III-IV
55	UMa	—	—	—	—	—	—	4.78	4.80	1.1	A2V
56	UMa	—	—	—	—	—	—	5.78	4.99	−1.9	G8II
57	UMa	—	—	—	—	—	—	4.78	5.31	1.1	A2V
58	UMa	—	—	—	—	—	—	5.78	5.94	3.3	F4V
59	UMa	—	—	—	—	—	—	5.78	5.59	−0.7	F2II-III
61	UMa	—	—	—	—	—	—	4.78	5.32	5.5	G8Vvar
62	UMa	—	—	—	—	—	—	5.78	5.70	3.3	F4V
66	UMa	—	—	—	—	—	—	5.78	5.84	0.1	K1III
67	UMa	—	—	—	—	—	—	4.78	5.22	—	A7m
70	UMa	—	—	—	—	—	—	5.78	5.55	−0.4	K5III
73	UMa	—	—	—	—	—	—	5.78	5.70	−1.1	M2III
74	UMa	—	—	—	—	—	—	5.78	5.40	—	A5e
76	UMa	—	—	—	—	—	—	5.78	6.02	−0.2	A2III
78	UMa	—	—	—	—	3.84	—	5.78	4.93	3.0	F2V
80g	UMa	—	—	—	—	—	4.75	4.78	4.01	1.8	A5V
81	UMa	—	—	—	—	—	—	5.78	5.60	0.6	A0V
82	UMa	—	—	—	—	—	—	5.78	5.40	1.7	A3Vn
83	UMa	—	—	—	—	—	—	5.45	4.66	—	M2IIIvar
84	UMa	—	—	—	—	—	—	5.78	5.70	—	B9pEuCr
86	UMa	—	—	—	—	—	—	5.78	5.69	0.6	A0V
α	UMa	2.08	1.91	1.90	1.81	1.84	1.08	1.78	1.79	−1.0	K0II-III+A8V:

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
β	UMa	2.08	2.58	2.57	1.81	1.84	1.75	2.11	2.37	0.5	A1V
γ	UMa	2.08	2.58	2.57	1.81	1.84	1.75	2.11	2.44	0.3	A0V
δ	UMa	3.08	3.24	3.23	1.81	1.84	2.08	3.11	3.31	1.9	A3Vvar
ε	UMa	2.08	1.91	1.90	2.14	1.84	2.75	1.78	1.77	—	A0pCr
ζ	UMa	2.08	1.91	1.90	1.81	1.84	2.75	1.78	2.06	—	—
η	UMa	2.08	1.91	1.90	1.81	1.84	2.75	1.78	1.86	—	B3V
θ	UMa	3.08	2.91	2.90	3.14	2.84	3.08	2.78	3.20	1.8	F6IV
ι	UMa	3.08	3.24	3.23	3.14	2.84	3.75	2.78	3.10	2.2	A7IV
κ	UMa	3.08	—	3.23	3.14	2.84	3.75	3.11	3.60	1.2	A1Vn
λ	UMa	3.08	3.24	3.23	3.48	3.84	3.08	3.11	3.40	0.6	A2IV
μ	UMa	3.08	3.24	3.23	3.48	3.84	2.75	2.78	3.05	−1.0	M0III
ν	UMa	3.08	3.24	3.23	3.48	3.84	3.75	3.11	3.47	−0.4	K3III
ξ	UMa	3.08	3.24	3.23	3.48	3.84	3.75	3.45	3.87	—	—
o	UMa	4.08	3.91	3.90	3.81	3.84	4.08	3.11	3.40	−0.7	G4II-III
π1	UMa	—	—	—	—	—	4.75	—	5.60	4.6	G1.5Vb
π2	UMa	5.08	4.91	4.90	3.81	3.84	5.75	—	4.60	0.1	K2III
ρ	UMa	5.08	4.91	4.90	3.81	3.84	4.75	4.78	4.76	−1.1	M3III
σ1	UMa	—	—	—	—	—	4.75	4.78	5.14	−0.7	K5III
σ2	UMa	5.08	4.91	4.90	3.81	3.84	4.75	4.78	4.80	3.4	F7IV-V
τ	UMa	4.08	3.58	4.23	—	3.84	4.75	4.45	4.60	—	Am
υ	UMa	4.08	3.91	3.90	3.81	3.84	3.75	3.45	3.80	1.7	F0IV
ϕ	UMa	4.41	4.24	4.23	3.48	3.84	4.75	4.45	4.59	0.9	A3IV
χ	UMa	—	—	—	—	3.84	3.75	—	3.71	0.2	K0III
ψ	UMa	3.75	3.24	3.23	3.81	3.84	3.08	2.78	3.00	0.1	K1IIII
ω	UMa	—	—	—	—	3.84	4.08	4.78	4.70	0.9	A1Vs
4b	UMi	—	—	—	—	—	4.75	4.78	4.82	−0.4	K3III
5a	UMi	4.08	3.91	3.90	—	—	3.75	4.45	4.25	−0.2	K4III
19	UMi	—	—	—	—	—	—	5.78	5.46	−0.2	B8V
24	UMi	—	—	—	—	—	—	5.78	5.79	—	A2m
α	UMi	3.08	2.91	2.90	1.81	1.84	2.75	1.78	2.02	—	F7:Ib-Iivar
β	UMi	2.08	1.91	1.90	1.81	1.84	2.75	1.78	2.05	—	K4IIIvar
γ	UMi	2.08	2.91	2.90	2.81	2.84	2.75	2.78	3.03	−1.1	A3II-III
δ	UMi	4.08	3.91	3.90	3.81	3.84	2.75	4.11	4.36	1.2	A1Vn
ε	UMi	4.08	3.91	3.90	3.81	3.84	3.75	4.11	4.23	—	G5IIIvar
ζ	UMi	4.08	3.91	3.90	3.81	3.84	3.75	4.11	4.32	1.7	A3Vn
η	UMi	4.08	4.58	4.57	4.81	4.84	4.75	4.78	4.95	3.4	F5V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
θ	UMi	—	—	—	—	5.84	4.75	5.45	4.96	−0.4	K5III
γ	Vel	2.08	1.91	1.90	—	—	—	—	1.69	—	—
δ	Vel	3.08	2.91	2.90	—	—	—	—	1.89	—	—
κ	Vel	3.08	3.91	3.90	—	—	—	—	2.50	−3.3	B2IV
λ	Vel	2.08	1.91	1.90	—	—	—	—	2.21	−3.0	K4Ib-II
o	Vel	3.08	2.91	—	—	—	—	—	3.63	−2.6	B3IV
ψ	Vel	2.41	2.91	2.90	—	—	—	—	3.60	2.5	F2IV
4A1	Vir	—	—	—	—	—	—	5.78	5.33	1.9	A1
6A2	Vir	—	—	—	—	—	—	5.78	5.58	0.2	K0III:
7b	Vir	—	—	—	—	5.84	5.08	5.78	5.37	1.2	A1V
10	Vir	—	—	—	—	—	—	5.78	5.95	−0.1	K3III
11	Vir	—	—	—	—	—	—	5.78	5.73	—	Am
12	Vir	—	—	—	—	—	—	5.78	5.80	—	A2m
16c	Vir	—	—	—	5.81	5.84	3.42	4.78	5.00	0.1	K1III
21q	Vir	—	—	—	—	5.84	5.75	5.78	5.48	0.6	A0V
25f	Vir	—	—	—	—	5.84	5.75	5.78	5.88	1.7	A3V
31d1	Vir	—	—	—	5.81	—	5.75	5.78	5.59	1.4	A2V
32d2	Vir	6.08	5.91	5.90	5.81	—	5.75	5.78	5.22	—	A8m
33	Vir	—	—	—	—	—	—	5.78	5.66	—	K1III-IV
41	Vir	—	—	—	—	—	—	5.78	6.25	0.2	A7III
44k	Vir	—	—	—	6.14	5.84	—	4.78	5.79	1.7	A3V
46	Vir	5.08	4.91	5.90	—	—	—	5.78	5.99	0.1	K2III
48	Vir	—	—	—	—	—	—	5.78	6.59	2.6	F0V
49g	Vir	5.08	4.91	4.90	—	5.84	4.75	4.78	5.19	0.1	K2III
53	Vir	6.08	5.91	5.90	—	—	—	4.78	5.04	1.4	F5III-IV
55	Vir	—	—	—	—	—	—	5.78	5.33	5.3	G6V
57	Vir	—	—	—	—	—	—	5.78	5.22	3.3	K1IV
59e	Vir	—	—	—	5.81	5.84	6.08	4.78	5.22	4.6	G0Vs
61	Vir	—	—	—	—	—	—	4.78	4.74	5.1	G6V
63	Vir	—	—	—	—	—	—	5.78	5.37	—	KIII
64	Vir	—	—	—	—	—	—	5.78	5.87	—	A2m
65	Vir	—	—	—	—	—	—	5.78	5.89	−0.1	K3III
66	Vir	—	—	—	—	—	—	5.78	5.61	2.8	F3V
68i	Vir	5.08	5.24	—	—	5.84	—	5.78	5.26	—	M0IIIvar
69	Vir	—	—	—	—	—	—	5.11	4.76	3.3	K1IIIvar
70	Vir	—	—	—	—	—	—	4.78	5.00	3.1	G5V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
71	Vir	—	—	—	—	—	—	5.78	5.65	−0.1	K0III
73	Vir	—	—	—	—	—	—	5.78	6.01	2.1	F0IV-V
74l2	Vir	5.08	5.24	5.23	5.48	5.84	5.75	4.78	4.69	−1.1	M2.5III
75	Vir	—	—	—	—	—	—	5.78	5.55	0.6	K1.5IIIb
76h	Vir	6.08	5.91	5.90	5.81	5.84	5.75	4.78	5.21	0.2	K0III
78o	Vir	—	—	—	5.81	5.84	5.75	4.78	4.94	—	A1pSrCrEu
80	Vir	—	—	—	—	—	—	5.78	5.73	0.4	G6III
82m	Vir	4.41	5.24	5.23	5.81	5.84	5.75	5.78	5.01	−0.9	M1.5III
83	Vir	—	—	—	—	—	—	5.78	5.57	−0.7	G0II-III
84	Vir	—	—	—	—	—	—	5.78	5.36	−0.2	K2III
86	Vir	5.08	5.24	5.23	—	—	—	5.78	5.51	—	G7III+(F1V)
88	Vir	—	—	—	—	—	—	5.78	6.5	—	K0
89	Vir	6.08	5.91	5.90	—	—	—	4.78	4.97	0.1	K1III
90p	Vir	5.08	4.91	4.90	5.81	5.84	5.75	5.45	5.15	0.1	K2III
92	Vir	—	—	—	—	—	—	5.78	5.90	2.4	A8V
95	Vir	—	—	—	—	—	—	5.78	5.46	1.9	F2IV
106	Vir	—	—	—	—	—	—	5.78	5.42	−0.4	K5III
108	Vir	—	—	—	—	—	—	5.78	5.70	0.4	B9.5V
109	Vir	—	—	—	—	—	—	3.45	3.72	0.6	A0V
110	Vir	—	—	—	—	—	—	4.78	4.40	0.2	K0III
β	Vir	3.08	2.91	2.90	2.81	2.84	2.75	3.11	3.61	3.6	F8V
γ	Vir	3.08	2.91	2.90	2.81	2.84	2.75	2.45	2.75	—	—
δ	Vir	3.08	2.91	2.90	2.81	2.84	2.75	2.78	3.38	−1.1	M3III
ε	Vir	2.75	2.91	2.90	2.81	2.84	2.75	2.45	2.83	—	G8IIIvar
ζ	Vir	3.08	3.24	3.23	2.81	2.84	5.75	3.11	3.40	1.7	A3V
η	Vir	3.08	2.91	2.90	3.81	3.84	2.75	3.11	3.89	0.3	A2IV
θ	Vir	4.08	4.91	3.90	3.81	3.84	3.75	4.11	4.38	0.9	A1V
ι	Vir	4.08	3.91	3.90	3.81	3.84	3.75	3.78	4.10	3.8	F7V
κ	Vir	4.08	3.91	3.90	3.81	3.84	3.75	4.11	4.19	−0.1	K3III
λ	Vir	4.08	3.91	3.90	3.81	3.84	3.75	4.45	4.52	—	A2m
μ	Vir	4.08	3.91	3.57	3.81	3.84	3.75	3.78	3.90	0.3	F2III
ν	Vir	5.08	4.91	4.90	4.81	4.84	4.75	4.11	4.03	−0.7	M0III
ξ	Vir	5.08	4.91	4.90	4.81	—	5.75	4.45	4.85	1.9	A4V
o	Vir	5.08	4.91	4.90	4.81	4.84	4.75	3.78	4.13	0.3	G8III
π	Vir	5.08	4.91	4.90	4.81	4.84	4.75	3.78	4.60	1.8	A5V
ρ	Vir	5.08	5.24	5.23	4.81	4.84	4.75	4.78	4.88	0.3	A0V

star		137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
σ	Vir	—	—	—	4.81	4.84	4.75	4.78	4.80	−1.1	M2III
τ	Vir	—	—	—	—	4.84	4.75	3.78	4.30	1.4	A3V
υ	Vir	—	—	—	4.81	—	—	4.78	5.14	0.3	G9III
ϕ	Vir	4.08	4.24	4.23	4.14	4.84	3.75	4.78	4.82	3.0	G2IV
χ	Vir	5.08	4.91	4.90	4.81	4.84	4.75	4.78	4.66	0.1	K2III
ψ	Vir	5.08	4.91	4.90	—	4.84	4.75	4.78	4.79	−0.6	M3IIIb+F6V
	Vir	—	—	—	—	5.84	5.75	5.78	5.36	−0.9	M4III
1	Vul	—	—	—	—	—	—	4.45	4.75	−2.3	B4IV
2	Vul	—	—	—	—	—	—	5.78	5.43	−4.2	B0.5IV
3	Vul	—	—	—	—	—	—	5.11	5.19	−1.9	B6III
4	Vul	—	—	—	—	—	—	4.78	5.16	0.2	K0III
5	Vul	—	—	—	—	—	—	5.78	5.63	0.3	A0V
9	Vul	—	—	—	—	—	—	4.78	5.02	−1.2	B8IIIn
10	Vul	—	—	—	—	—	—	5.78	5.49	0.3	G8III
12	Vul	—	—	—	—	—	—	4.78	4.94	−2.1	B2.5V
13	Vul	—	—	—	—	—	—	4.45	4.58	−1.0	B9.5III
14	Vul	—	—	—	—	—	—	5.45	5.60	2.1	F0
15	Vul	—	—	—	—	—	—	4.78	4.70	−0.2	A4III
16	Vul	—	—	—	—	—	—	4.78	5.22	0.6	F2III
17	Vul	—	—	—	—	—	—	5.11	5.06	−2.0	B3V
18	Vul	—	—	—	—	—	—	5.78	5.52	−0.3	A3III
19	Vul	—	—	—	—	—	—	5.78	5.49	−1.1	K3II-III
20	Vul	—	—	—	—	—	—	5.78	5.91	−0.6	B7Ve:
21	Vul	—	—	—	—	—	—	5.45	5.16	1.5	A7IVn
22	Vul	—	—	—	—	—	—	5.78	5.13	—	G3Ib-II+B7/9
23	Vul	—	—	—	—	—	—	4.78	4.52	−0.1	K3III
24	Vul	—	—	—	—	—	—	5.78	5.32	0.3	G8III
25	Vul	—	—	—	—	—	—	5.78	5.52	−1.2	B8IIIn
27	Vul	—	—	—	—	—	—	5.45	5.59	−0.1	B9V
28	Vul	—	—	—	—	—	—	5.11	5.03	−1.6	B5IV
29	Vul	—	—	—	—	—	—	4.78	4.82	0.6	A0V
30	Vul	—	—	—	—	—	—	5.45	4.91	−0.2	K2III
31	Vul	—	—	—	—	—	—	4.78	4.59	0.0	G8III
32	Vul	—	—	—	—	—	—	5.11	5.01	−0.2	K4III
33	Vul	—	—	—	—	—	—	5.45	5.31	−0.1	K3.5III
35	Vul	—	—	—	—	—	—	5.45	5.41	1.2	A1V

star	137	964	1437	1572	1603	1689	1843	m_{2000}	M_V	spectral type
α Vul	—	—	—	—	—	—	4.11	4.44	—	M0comp

Note

1) Due to our inquiry to the staff of Simbad, the classification of α sgr was revised.

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文献学的方法による恒星の長期間変動の探査

藤　原　智　子

要　旨

写真乾板を使った恒星の測光観測が始まったのは，今からまだ 100 年余り前の事で，それ以前の天体現象は全て星表や星図，又は記述の形でしか残されていない．それ故，100 年 1000 年以上のオーダーで変光する星は現在まだ見つかっていないが，これは 100 年を超えるタイムスケールで変光する星が存在しない事を支持するものではない．本研究は，有史以来の天文書に残されている恒星の等級データを分析して変動天体を検出し，そのメカニズムの解明を目指すものである．

まず，7 つの古文献を使い，延べ 2123 の恒星の等級データを抽出し，観測の独立性を証明した．次にこれらの古文献を現代の恒星カタログのデータと比較し，等級データの信頼性を確認した．等級の違いが算出された標準偏差よりも充分大きければ，等級変化はリアルであると考えられる．そして統計テストの結果から，古文献に記録された恒星の等級データは科学研究に利用出来るものと判断した．

次に古文献に於ける等級システムについて議論した．文献のデータが現在の等級システムである Pogson の log スケールに沿うのか，power-law スケールに沿うのか，補正 χ 二乗テストに基づいて調査した．その結果，全ての古文献の等級システムは log スケールに合い，光比もほぼ Pogson の値と一致する事が分かった．

最後に全ての恒星の等級を年代毎に比較した．2123 個の恒星のうち，殆どの星が無変化若しくは極小さい変動しか示さない中で，3 等以上の等級変動を見せた星が 8 つあった．その中でも特に α Sgr は 4 等近くの大きな変動を見せた．この星は B 型の主系列星であり，恒星内に起因する変動であるとは考え難い．また連星でもない為，この変動は外因的なものと推定される．この星は星周物質に取り囲まれており，その吸収による赤外超過が報告されているが，これに起因する大きな光度上昇があったとはやはり考え難い．この変動の痕跡が，星周物質の構造に残されていると考えられるので，天体自身及びその周囲の物理的状態をより詳しく知る為の詳細かつ多面的な観測データが不可欠である．

キーワード：変光星，突発天体，歴史的星表，恒星の等級，測光