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978-0-521-89954-3 - Stars and Their Spectra: An Introduction to the Spectral Sequence Second Edition
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Excerpt
More information

1 *Stars*

OBAFGKM. Anyone who studies the stars quickly encounters this seemingly mystical series of letters that divides stars into their classic groups, now expanded to OBAFGKMLT, even to MLTY. This alphabet of stellar astronomy, the sequence of stellar spectral types, is the foundation that supports our organized knowledge of the stars. What does this basic sequence of letters mean? Where did it originate, and why is it so valuable? How does it serve to differentiate one kind of star from another? How has it been embellished over the years, such that more than a century after it was introduced it is still vital and growing? Here we explore these and other questions, both from a historical point of view and from the perspective of modern observational and theoretical astrophysics, wherein theory is incorporated into, and developed from, a foundation of morphological astronomy. No matter how carefully we otherwise observe stars, we cannot begin to know them until we can comprehend their spectra, through which their real physical natures are revealed. It is through the spectra, and equally through their classification, that we began – and continue – to learn about stars.

Stars at first appear to be the primary depositories of mass in the Universe. After all, when we look at the sky through our telescopes, the stars – and the related interstellar clouds from which they spring – dominate our view. Even vast clusters of distant galaxies seem to be owned by them. Alas. For all those who love them, the stars are not ascendant. They are not even close. Nearly 10 times as much matter is in a form not readily visible, much (if not all) of it in hot gas within dense galaxy clusters. Another five to six times more seems to be in some form of *dark matter* that pervades and encloses galaxies and their clusters. We know next to nothing about it except that it has a powerful gravitational pull that began to be recognized in the mid 1930s. If we wish be more exotic, three times more than the sum of the masses of normal plus dark matter is in the mass equivalent of the *dark energy* that seems to be accelerating the expansion rate of the Universe.

Why, then, study stars? First, and clearly most important, we owe our lives to one, our own Sun. And we come to know it better by examining all the other stars, to see where "our star" fits in. Second, though stars may not dominate in mass,

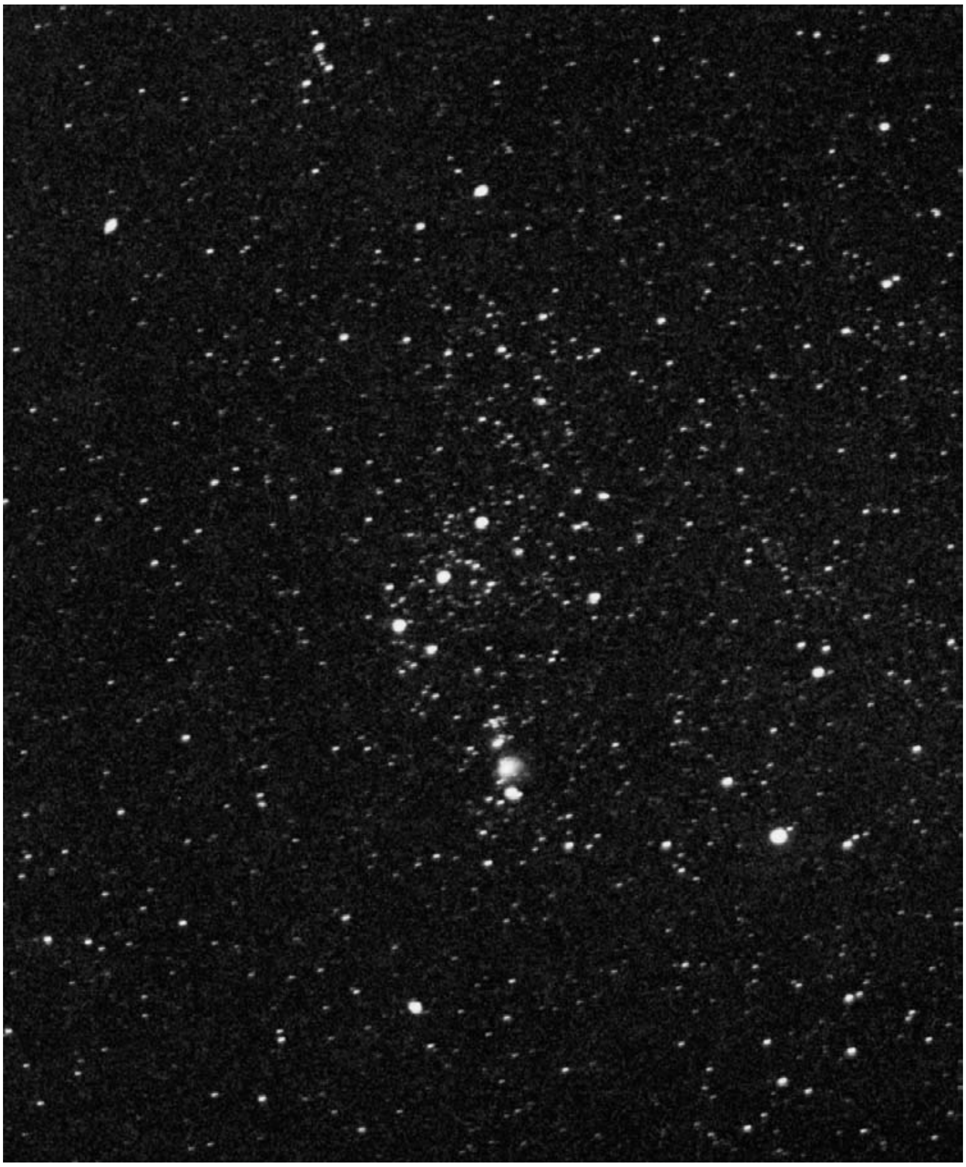

Figure 1.1 The classic seven-star figure of Orion. This instantly recognizable constellation lies at the western edge of the Milky Way. Visible, at least in part, from anywhere on Earth, it epitomizes stellar astronomy. Most of its stars are hot and blue, including those of the three-star Belt and supergiant Rigel at lower right. Betelgeuse, a red supergiant, glows at upper left. The diffuse patch below the Belt is the great Orion Nebula, a huge cloud of interstellar gas associated with recent star formation. Author's photo.

they *do* track the mysterious dark matter, and they thus show us how mass is distributed. Third, the stars are the birthplaces of the chemical elements, everything that made the Earth and ourselves. Moreover, we can *see* them. And they are beautiful (Figure 1.1).

1.1 The natures of stars

Precisely defining a "star" is surprisingly complex. At the heart of it, a star is a massive gaseous body (the Sun "weighing in" at 330 000 Earths) supported and illuminated by an interior nuclear furnace that (like the Sun's) transforms one chemical element into another, and, as a result, mass into energy. We then broaden the definition to encompass any body that ever operated in such a fashion or that ever will do so, allowing us to incorporate into the fold both dead stars and those caught in the act of being born.

The definition then becomes greyer. Low mass bodies (a few percent solar) incapable of running the nuclear furnace might still be thought of as "stars" if they formed like ordinary "real" stars, directly by condensation from interstellar matter. Massive planets, however, might become hot enough inside to run at least some form of the nuclear furnace, but they remain "planets" if they were formed, as our Earth, Jupiter, and Saturn seem to have been, from the initial accumulation of dust grains in gaseous, circumstellar disks. To avoid such confusion, additional nomenclature is needed, some already in place.

Given that "we know a star when we see one," the nearest of stars, the Sun, though above average in all properties, is still typical in all sorts of ways (Figure 1.2). It is one and one half million kilometers – 109 Earth diameters – across. Its mass is 2×10^{33} grams, a third of a million times that of Earth. From a distance of 150 million kilometers, its 5800 K surface sends us enough radiation from a total luminosity of 4×10^{26} watts to liquify terrestrial water and make all life possible. (Degrees Kelvin, K, or kelvins are centigrade degrees above absolute zero, −273 °C.) Although sunlight derives from nuclear fusion reactions that together act like a remarkably well-controlled hydrogen bomb, we can see none of that action itself. The nuclear energy is generated in the deep inner quarter, and the radiation we observe has taken hundreds of thousands of years to work its way through the vast outer envelope to the surface.

Although the stars in general take on a supremely unchanging mien, they are actually constantly undergoing steady alterations as their fuel supplies are used up. We are fooled into thinking of them as steadfast because human existence is so short compared with the times over which stars live normal lives: 10 billion years for the Sun. The Sun, like most others, is in a particularly stable stage of its life, one called the "main sequence," in which stars fuse internal hydrogen into helium. Other stars have passed through this period of stability and are dying, which causes enormous, though still slow, changes to occur. The result, coupled with nature's penchant for producing stars over an enormous range of masses, is an array of bodies with vastly different characteristics.

Indeed, the most important physical quantity possessed by a star *is* its mass, which largely foretells the entire road over which it will travel during its life, as well as the age it will reach before it dies. The Sun is in the middle of a distribution that (using the extended definition) runs roughly from a hundredth of a solar mass to a poorly defined upper limit that well tops 100 Suns. For normal main sequence stars, surface temperatures range from roughly 3000 K, for the

Figure 1.2 Our Sun. Sustaining nearly all life on Earth, our star has been shining for the past 4.6 billion years under the control of internal nuclear reactions that convert hydrogen to helium. It has another 5½ billion years to go before the fuel runs out and it begins to die. Author's photo.

coolest, to 50 000 K. In the extreme, the range can go from as low as a few hundred K for ultra-low-mass "substars" to as high as a million kelvins for highly evolved bodies. The lowest main sequence mass stars radiate feebly, with total energy outputs that are but a ten-thousandth solar. None are visible to the eye at all. At the high end, extraordinary beacons gleam millions of times brighter than the Sun such that they are easily visible over vast intergalactic distances. And that does not count the ones that explode.

The disparity in dimensions is even greater. We see shrunken, dead corpses of once-normal stars that are comparable to Earth in size, and a few far more rare that are no larger than a small city. At the other end, swollen giants that are in their death throes would take in nearly the orbit of Saturn. Even the ages differ, with our 4.6-billion-year-old Sun (about half way through its life) again in the middle. Some stars, nearly three times the age of the Sun, are as old as the Galaxy. At the other end, we see them being born as we watch.

This great variety is surprisingly comprehensible. Over the past century we have been able to codify stars, their characteristics, and their present places in the scheme of stellar evolution. Our tool is the spectrum, which has allowed a distinctive taxonomy of stars, in which they are divided into nine basic groups, the famed OBAFGKMLT, plus the various addenda and subclasses to which we will return.

1.2 Common names

Star names at first present a picture of chaos in that a number of systems are in use. The three most common ways of naming stars refer in some way to their resident *constellations*. Constellations are named patterns of stars. Just over half (50) of the 88 recognized figures are from lost ancient times, and represent myths and sacred symbolism. Outstanding examples are the famed figures of the Zodiac (Scorpius the Scorpion, Leo the Lion), Orion the Hunter (Figure 1.1) with his two dogs (Canis Major and Minor), and the bears (Ursa Major and Minor), which contain the well-known informal Big and Little Dippers. The remaining 38 constellations were added in the seventeenth and eighteenth centuries to fill the huge void in the southern hemisphere as well as the dim areas of sky in the northern hemisphere that the ancients did not see fit to name. Table 1.1 lists the full set of constellations formally adopted around 1930 by the International Astronomical Union, which also assigned boundaries.

The brightest stars are still known by their old proper names, which issue from a variety of ancient languages (chiefly Arabic) and that are typically characteristic of the appearance of the star, or of its placement within its constellation. In Arabic, “Deneb” means “tail,” appropriate to its end position in the constellation Cygnus the swan (Figure 1.3). These names for the twenty or so brightest stars (Table 1.2) are common in the astronomical literature.

A more systematic method, developed by the Bavarian astronomer Johannes Bayer (1564–1617) for his great atlas, the *Uranometria* of 1603, uses Greek letters attached to the Latin genitive (possessive form) of the constellation name (Table 1.3). Thus Deneb, the brightest star in Cygnus, becomes Alpha (α) of Cygnus, or α Cygni (and by abbreviation, α Cyg). Table 1.1 gives both possessives and abbreviations. Bayer’s stars are nominally lettered in order of brightness (“α” usually the constellation’s luminary), but he often as not used position or some system known only to himself. The scheme is extended somewhat from its 24 Greek letters by the use of numerical superscripts for neighboring stars, e.g. π^1 through π^6 Orionis. Though Bayer followed the Greek letters with Roman ones, these are only rarely used. Later astronomers assigned Greek letters in southern-hemisphere constellations.

Table 1.1 *The Constellations*

Asterisks denote the "Ancient 48" (50 with the breakup of Argo) whose origins are lost to antiquity. The others are of modern origin, invented in the seventeenth and eighteenth centuries to fill in the relatively blank areas of sky and give names to southern groups not visible from the latitudes of our ancient predecessors. Some prominent famous groups are parts of larger constellations: for example the Big and Little Dippers belong to Ursa Major and Ursa Minor.

Name	Meaning	Genitive	Abbreviation
*Andromeda[a]	Chained lady	Andromedae	And
Antlia	Air pump	Antliae	Ant
Apus	Bird of paradise	Apodis	Aps
*Aquarius[b]	Water bearer	Aquarii	Aqr
*Aquila	Eagle	Aquilae	Aql
*Ara	Altar	Arae	Ara
*Aries[b]	Ram	Arietis	Ari
*Auriga	Charioteer	Aurigae	Aur
*Boötes	Herdsman	Boötis	Boo
Caelum	Engraving tool	Caeli	Cae
Camelopardalis	Giraffe	Camelopardalis	Cam
*Cancer[b]	Crab	Cancri	Cnc
*Canes Venatici	Hunting dogs	Canum Venaticorum	CVn
*Canis Major	Larger dog	Canis Majoris	CMa
*Canis Minor	Smaller dog	Canis Minoris	CMi
*Capricornus[b]	Water goat	Capricorni	Cap
*Carina[c]	Keel of Argo	Carinae	Car
*Cassiopeia[a]	Queen	Cassiopeiae	Cas
*Centarus	Centaur	Centauri	Cen
*Cepheus[a]	King	Cephei	Cep
*Cetus[a]	Whale	Ceti	Cet
Chamaeleon	Chameleon	Chamaeleontis	Cha
Circinus	Compasses	Circini	Cir
Columba	Dove	Columbae	Col
Coma Berenices	Bernices hair	Comae Berenices	Com
*Corona Australis	Southern crown	Coronae Australis	CrA
*Corona Borealis	Northern crown	Coronae Borealis	CrB
*Corvus	Crow	Corvi	Crv
*Crater	Cup	Crateris	Crt
Crux	Southern cross	Crucis	Cru
*Cygnus	Swan	Cygni	Cyg
*Delphinus	Dolphin	Delphini	Del
Dorado	Swordfish	Doradus	Dor
*Draco	Dragon	Draconis	Dra
*Equuleus	Little horse	Equulei	Equ
*Eridanus	River	Eridani	Eri

Table 1.1 (*Continued*)

Name	Meaning	Genitive	Abbreviation
Fornax	Furnace	Fornacis	For
*Gemini[b]	Twins	Geminorum	Gem
Grus	Crane	Gruis	Gru
*Hercules	Hero; Hercules	Herculis	Her
Horologium	Clock	Horologii	Hor
*Hydra	Water serpent	Hydrae	Hya
Hydrus	Water snake	Hydri	Hyi
Indus	Indian	Indi	Ind
Lacerta	Lizard	Lacertae	Lac
*Leo[b]	Lion	Leonis	Leo
Leo Minor	Smaller lion	Leonis Minoris	LMi
*Lepus	Hare	Leporis	Lep
*Libra[b]	Scales	Librae	Lib
*Lupus	Wolf	Lupi	Lup
Lynx	Lynx	Lyncis	Lyn
*Lyra	Lyre	Lyrae	Lyr
Mensa	Table	Mensae	Men
Microscopium	Microscope	Microscopii	Mic
Monoceros	Unicorn	Monocerotis	Mon
Musca	Fly	Muscae	Mus
Norma	Square	Normae	Nor
Octans	Octant	Octantis	Oct
*Ophiuchus	Serpent bearer	Ophiuchi	Oph
*Orion[a]	Hunter	Orionis	Ori
Pavo	Peacock	Pavonis	Pav
*Pegasus[a]	Winged horse	Pegasi	Peg
*Perseus[a]	Hero; Perseus	Persei	Per
Phoenix	Phoenix	Phoenicis	Phe
Pictor	Easel	Pictoris	Pic
*Pisces[b]	Fishes	Piscium	Psc
*Piscis Austrinus	Southern fish	Piscis Austrini	PsA
*Puppis[c]	Stern of Argo	Puppis	Pup
Pyxis	Compass	Pyxidis	Pyx
Reticulum	Net	Reticuli	Ret
*Sagitta	Arrow	Sagittae	Sge
*Sagittarius[b]	Archer	Sagittarii	Sgr
*Scorpius[b]	Scorpion	Scorpii	Sco
Sculptor	Sculptor's studio	Sculptoris	Scl
Scutum	Shield	Scuti	Sct
*Serpens[d]	Serpent	Serpentis	Ser
Sextans	Sextant	Sextantis	Sex

(*continued*)

Table 1.1 (*Continued*)

Name	Meaning	Genitive	Abbreviation
*Taurus[b]	Bull	Tauri	Tau
Telescopium	Telescope	Telescopii	Tel
*Triangulum	Triangle	Trianguli	Tri
Triangulum Australe	Southern triangle	Trianguli Australis	TrA
Tucana	Toucan	Tucanae	Tuc
*Ursa Major	Larger bear	Ursa Majoris	UMa
*Ursa Minor	Smaller bear	Ursae Minoris	UMi
*Vela[c]	Sails of Argo	Velorum	Vel
*Virgo[b]	Maiden	Virginis	Vir
Volans	Flying fish	Volantis	Vol
Vulpecula	Fox	Vulpeculae	Vul

[a] In Greek mythology, Andromeda was the daughter of Cepheus and Cassiopeia, King and Queen of Ethiopia, who was saved from Cetus by Perseus (a son of Zeus), who saw her while he was riding on Pegasus when returning from killing the Medusa. Orion was a hunter who chased the Pleiades and who was slain by Diana (or Scorpius).
[b] Constellation of the Zodiac, the band of constellations that contains the ecliptic (the apparent annual path of the Sun). Though the ecliptic passes through Ophiuchus, it is not a part of the classical Zodiac.
[c] Carina, Puppis, and Vela are modern subdivisions of the large constellation Argo Navis, the legendary ship of the Argonauts. The modern constellation Pyxis is sometimes considered to be a part of it.
[d] Contains two parts separated by Ophiuchus; Serpens Caput, the Head of the Serpent, is the western half, while Serpens Cauda, the Tail, is the eastern half. It is still considered to be one constellation.

1.3 Location

Just specifying position within a constellation is hardly sufficient. More comprehensive measures require *coordinates*. The most common system involves a simple analogue of terrestrial latitude and longitude. We define celestial poles and a celestial equator that lie above the Earth's rotation poles and equator. We next establish a fundamental circle on the sky akin to the prime meridian on Earth, one that runs between the poles through the Vernal Equinox (the basic celestial reference point where the Sun crosses the equator on its way north). We then pass another meridian, an *hour circle*, through the star whose coordinates are to be specified.

The angle between the Vernal Equinox and the point where the hour circle crosses the celestial equator is the star's *right ascension* (alpha, α). It is usually measured in time units (hours, minutes, and seconds), where one hour equals 15°, one degree equals 4 minutes (m), etc. The angle from the equator to the star, measured north or south (+ or −) in degrees along the hour circle, is the star's

Table 1.2 *The first-magnitude stars*

The first-magnitude stars (including the Sun) are listed below by apparent visual magnitude (V) according to the Yale *Bright Star Catalogue* (see Section 1.9). The list then also gives color (B–V), distance mostly from updated Hipparcos parallaxes (D, in parsecs, those of Hadar and Betelgeuse from the literature), absolute visual magnitude (M_V, see Sections 1.8 and 1.9; corrected for interstellar dust absorption where necessary), and the spectral class (see Chapter 3). Separate binary components are listed for α Centauri and α Crucis, which have respective combined apparent visual magnitudes of −0.29 and 0.8. Proxima Centauri, an 11th-magnitude companion to α Cen, is actually the closest star (other than the Sun) to Earth. Capella and Spica are both closely spaced doubles, while Betelgeuse and Antares are both variables. The meanings of the names, from Arabic, Greek, and Latin, are primarily from *Short Guide to Modern Star Names and their Derivations*, Paul Kunitzsch and Tim Smart, Wiesbaden, Otto Harrassowitz, 1986. Those not from Arabic (or are obvious) are labeled with (L) for Latin, (G) for Greek.

Bayer name	Proper name	Meaning	V	B–V	D (pc)	M_V	Spectrum
. . .	Sun	. . .	−26.75	0.65	1 AU	4.83	G2 V
α Canis Majoris	Sirius	Searing (G)	−1.46	0.00	2.64	1.43	A1 V
α Carinae	Canopus	Proper name (G)	−0.72	0.15	95	−5.60	F0 II
α Centauri A	Rigil Kentaurus	Foot of centaur (G)	−0.01	0.71	1.35	4.34	G2 V
α Centauri B	. . .	. . .	1.33	0.88	1.35	5.68	K1 V
α Boötis	Arcturus	Bear driver (G)	−0.04	1.23	11.3	−0.30	K1.5 III
α Lyrae	Vega	Swooping eagle	0.03	0.00	7.7	0.60	A0 V
α Aurigae	Capella	She-goat (L)	0.08	0.80	13.1	−0.51	G8 III + G0 III
β Orionis	Rigel	Foot of central one	0.12	−0.03	265	−7.0	B8 Iab
α Canis Minoris	Procyon	Before the dog (G)	0.34	0.42	3.5	2.61	F5 IV–V
α Eridani	Achernar	End of river	0.46	−0.16	44	−2.70	B3 Vpe
β Centauri	Hadar	. . .	0.61	−0.23	120	−4.81	B1 III
α Orionis	Betelgeuse	Hand of central one	0.7	1.85	135	−5.5	M2 Iab
α Aquilae	Altair	Flying eagle	0.77	0.22	5.1	2.22	A7 V
α Crucis A	Acrux	Alpha Crucis	1.3	0.26	100	−3.9	B0.5 IV
α Crucis B	. . .	. . .	1.8	0.2	100	−3.4	B1 V
α Tauri	Aldebaran	Follower	0.85	1.54	20.1	−0.70	K5 III

(*continued*)

Table 1.2 (*Continued*)

Bayer name	Proper name	Meaning	V	B–V	D (pc)	M_V	Spectrum
α Scorpii	Antares	Like Mars (L)	0.96	1.83	170	−5.7	M1.5 Ib
α Virginis	Spica	Sheaf of wheat (L)	1.04	−0.23	77	−3.38	B1 V + B4 V
β Geminorum	Pollux	Proper name (G)	1.14	1.00	10.4	1.06	K0 III
α Piscis Austrini	Fomalhaut	Fish's mouth	1.16	0.09	7.7	1.73	A3 V
α Cygni	Deneb	Tail	1.25	0.09	435	−7.1	A2 Ia
β Crucis	Mimosa	. . .	1.25	−0.23	85	−3.41	B0.5 III
α Leonis	Regulus	Little king (L)	1.35	−0.11	24	−0.58	B7 V
ε Canis Majoris	Adhara	The virgins	1.50	−0.21	124	−4.03	B2 II

declination (delta, δ), where the sky's northern or southern hemispheres are indicated by N and S, or by plus and minus. The coordinates of Deneb are $\alpha = 20^{h}\ 41^{m}\ 25.8^{s}$, $\delta = +45°\ 16'\ 49''$, where there are 60 minutes (′) per degree and 60 seconds (″) per minute, these terms not to be confused with time units.

Because of precession, the 26 000-year wobble of the Earth's axis, the Vernal Equinox moves westerly against the stellar background. The coordinates thus change with time (as evident from Figure 1.3), so that we must also specify a date (the *epoch*) for which they are valid. For those of Deneb above, the epoch is the beginning of the year 2000. Since we know how right ascension and declination change, we can easily calculate what they should be for any moment in question.

1.4 General catalogues

The first comprehensive naming method, which still uses the constellations, comes to us from the English astronomer John Flamsteed (1646–1719). Making precise telescopic measures of positions, he ordered more than a third of the naked-eye stars from west to east within the constellations he could see from his northern observatory (Figure 1.3). Newton and Halley then assigned numbers. Thus Deneb = α Cyg is also 50 Cygni, Vega = α Lyrae = 3 Lyrae. The Bayer letters almost always take precedence.

When the Flamsteed numbers are unavailable (and often when they are), we rely on numbers from catalogues that are divorced from the constellations. The *Bonner Durchmusterung* (Bonn Survey), which contains nearly half a million stars, named them from west to east within one-degree declination strips according to 1855 coordinates. Deneb is also then BD (or DM) +44°3541. That Deneb's modern