Chapter 2

Astronomy and astrophysics

The Solar System	25
The Sun	25
Solar System elemental abundances	30
The planets (physical elements)	31
The planets (orbital elements)	32
Natural satellites in the Solar System	33
Short period comets	36
Principal meteor streams	37
Stars	38
Star charts	38
Constellations	40
The brightest stars	44
The 100 visually brightest stars	45
Stars within 5 pc	50
Nearest stars	52
Stars of large proper motion	53
The 21 fastest pulsars	54
Pulsars	56
Binary radio pulsars	58
OB associations	59
Orbital elements of binary stars	61
Classification of variable stars	62
Galactic supernova remnants	64
Henry Draper spectral classification	64
Spectral type and luminosity class	65
Hertzsprung–Russell diagram	66
Infrared and visible spectral features	67
The main sequence	68

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Giant stars 70
Classification and absolute magnitude of stars 71
Stellar mass, luminosity, radius and density 72
Present-day mass function 74
Star number densities 76
Relative number of stars 78
Integrated star light 78
Mean star density vs visual magnitude 79
Star counts 80
Luminosity functions 80
Parameters of the interstellar gas 81
Galaxies 82
Properties of the galaxy 82
The local group 83
Hubble's classification 84
Nearby extragalactic objects 84
Selected brighter galaxies 85
Named galaxies 86
Representative active galactic nuclei 87
Objects with large redshifts 90
Prominent clusters of galaxies 91
Energy content of constituents of space 93
Mass–radius–density data for astronomical objects 94
The Messier catalog 95
Astronomical photometry 98
Standard photometric systems 100
Interstellar reddening 103
Absolute magnitude 105
Moon, night sky, sun, and planetary brightness 105
Spherical astronomy 107
Time 107
The clelestial sphere 109
Celestial coordinates 110
The Zodiac 110
Astronomical coordinate transformations 111
Approximate reduction of astronomical coordinates 113
Major ground-based astronomical facilities 114
The Hubble Space Telescope 120
Description of the Hubble Space Telescope 121
Glossary of astronomical terms 124
Bibliography 140

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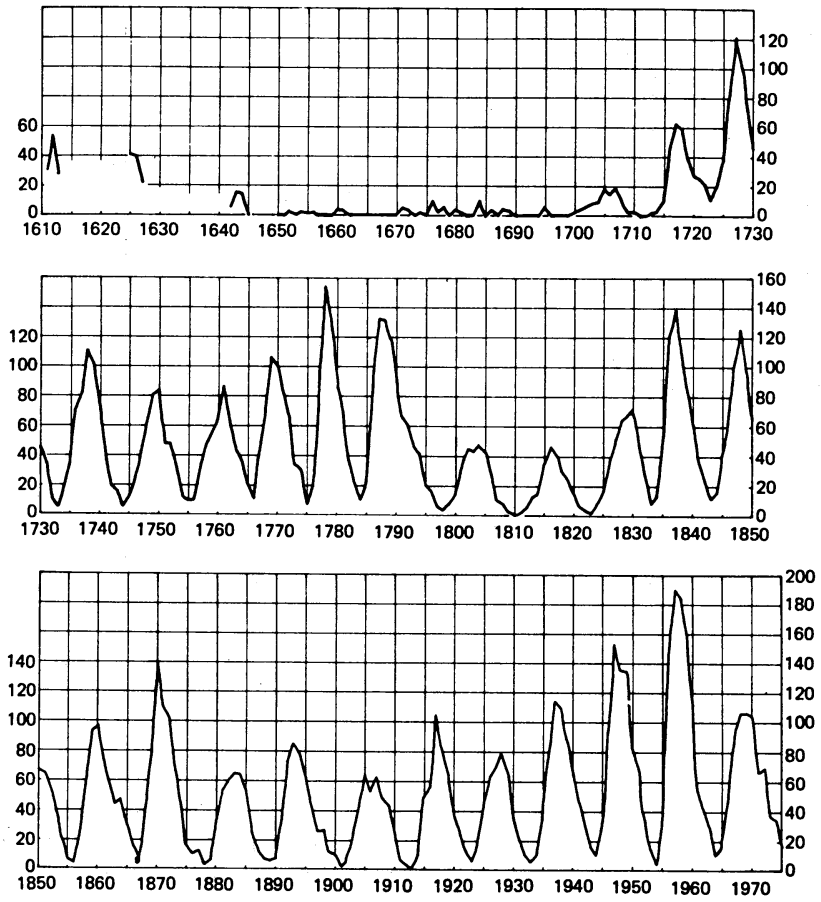
The Sun

Mass	1.9891×10^{33} g
Radius	6.9599×10^{10} cm
Magnetic field strengths (typical):	
Sunspots	3000 G
Polar field	1 G
Bright, chromospheric network	25 G
Ephemeral (unipolar) active regions	20 G
Chromospheric plages	200 G
Prominences	10–100 G
Mean density	1.410 g cm^{-3}
Gravity at surface	2.7398×10^{4} cm s^{-2}
Mean distance from Earth	1 AU = $1.495\,98 \times 10^{13}$ cm
Solar constant (1980)	0.1368 watts cm^{-2}
M_v	+4.83
m_v	−26.74
M_{bol}	+4.75
m_{bol}	−26.82
Effective temperature	5770 K
Luminosity	3.826×10^{33} erg s^{-1}
Spectral type	G2 V
Inclination of equator to ecliptic	7° 15′
Sidereal rotation (func. of lat.)	$14°.44 - 3°.0 \sin^2 \phi$ per day
Synodic rotation (func. of lat.)	$13°.45 - 3°.0 \sin^2 \phi$ per day
Central density	140–180 g cm^{-3}
Central temperature	$(14.9–15.7) \times 10^{6}$ K
Surface area	6.087×10^{22} cm^2
Volume	1.412×10^{33} cm^3
Moment of inertia	5.7×10^{53} g cm^2
Specific surface emission	6.329×10^{10} erg cm^{-2} s^{-1}
Specific mean energy production	1.937 erg g^{-1} s^{-1}
Escape velocity at surface	6.177×10^{7} cm s^{-1}

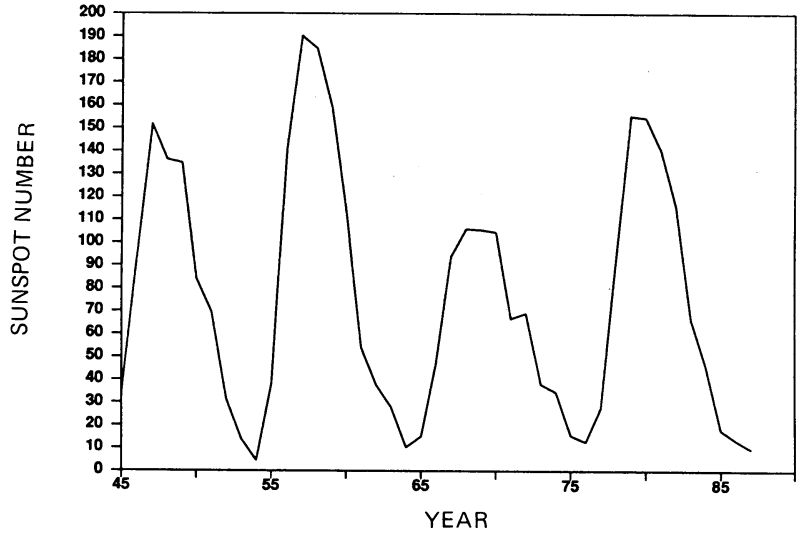
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The Sun *(cont.)*

Annual mean sunspot number, AD 1610–1975. (From Eddy, J. in *The Solar Output and its Variation*, O. White, ed., Colorado Association University Press, 1977.)



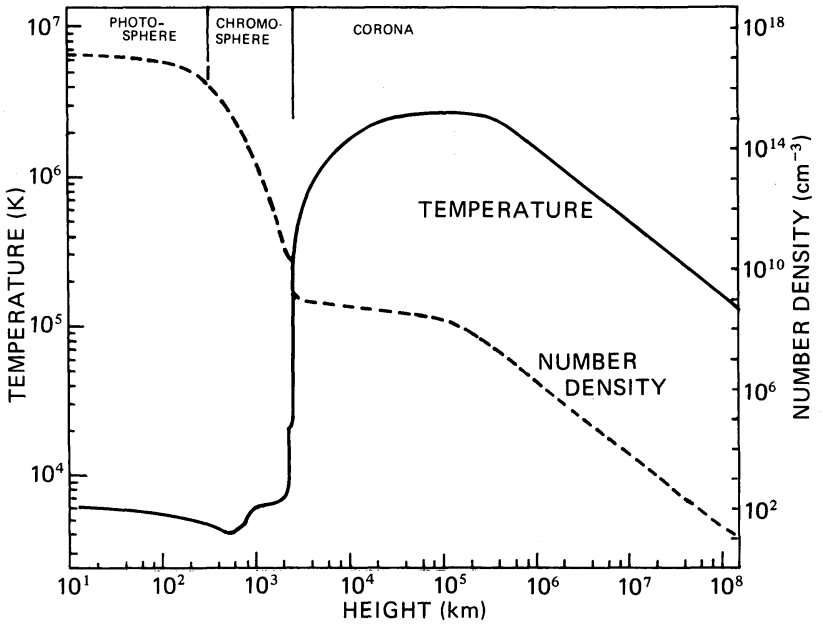
Yearly mean sunspot numbers 1945–87. (US Department of Commerce.)



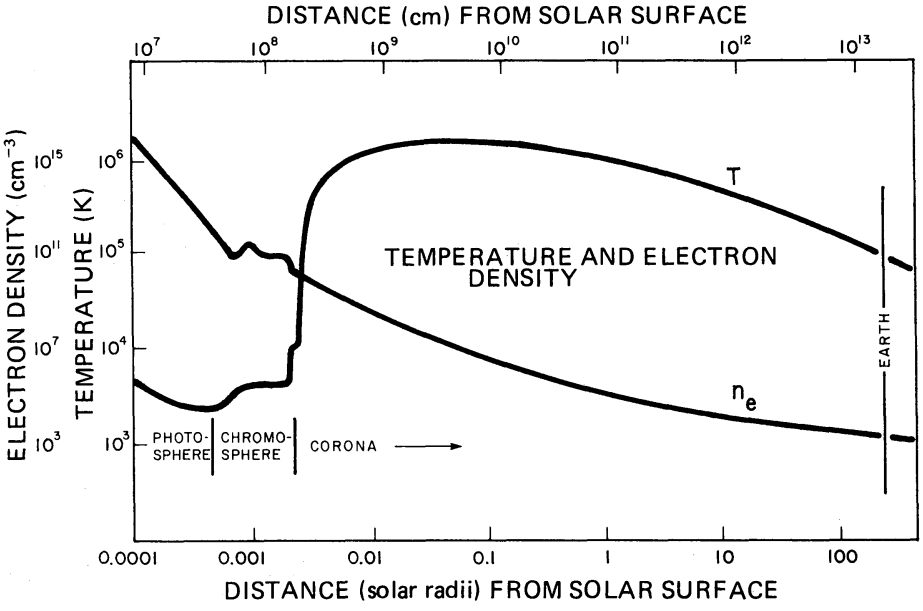
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The Sun *(cont.)*

Temperature and density as a function of distance from the solar surface. (Courtesy of G. Withbroe, Harvard/Smithsonian Center for Astrophysics.)



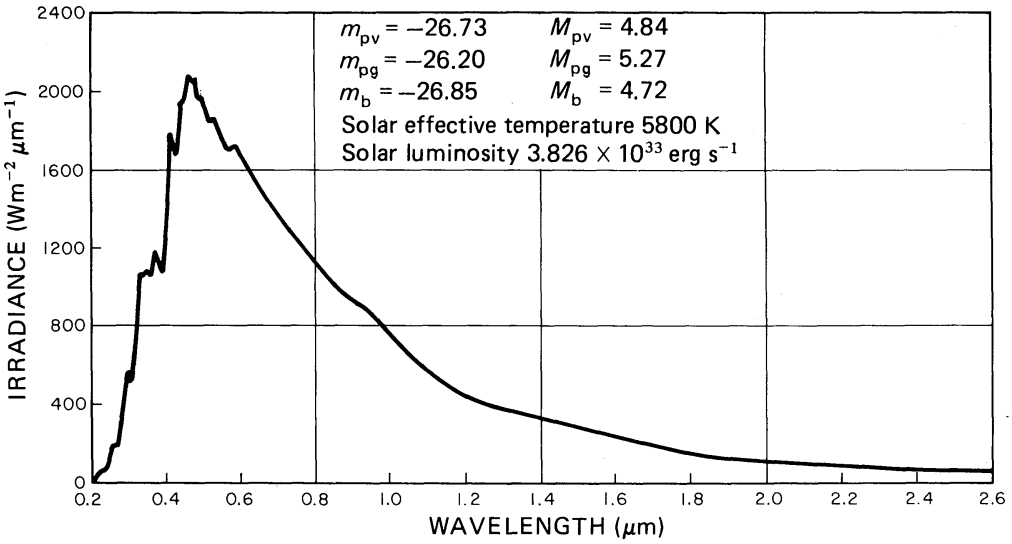
Solar temperature and electron density. (Adapted from Carrigan, A. L. & Skrivanek, *Aerospace Environment*, Air Force Cambridge Research Laboratories, Massachusetts, 1974.)



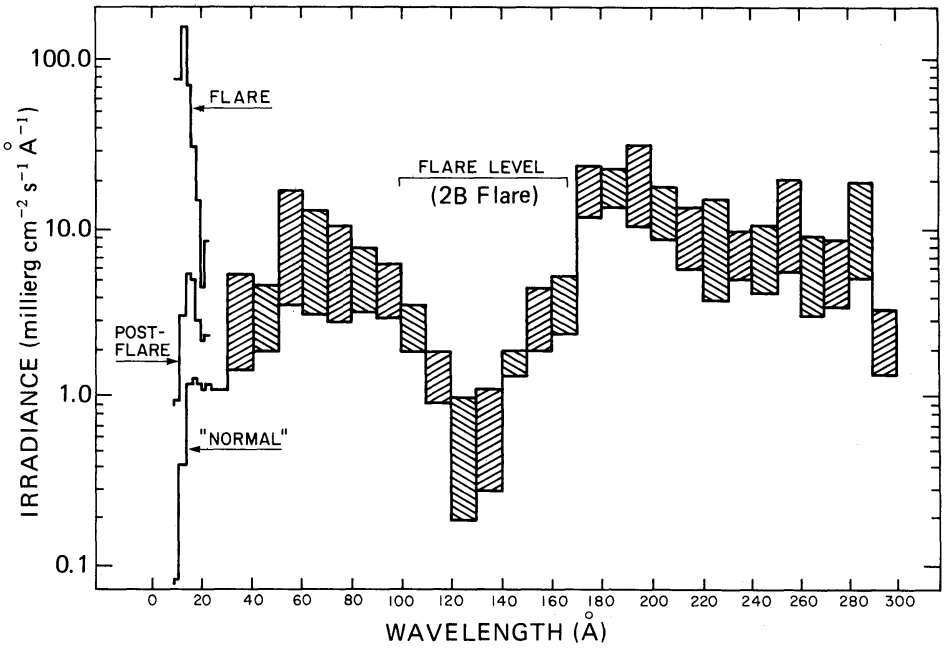
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The Sun *(cont.)*

Solar spectral irradiance. (Adapted from Carrigan, A. L. & Skrivanek, *Aerospace Environment*, Air Force Cambridge Research Laboratories, Massachusetts, 1974.)



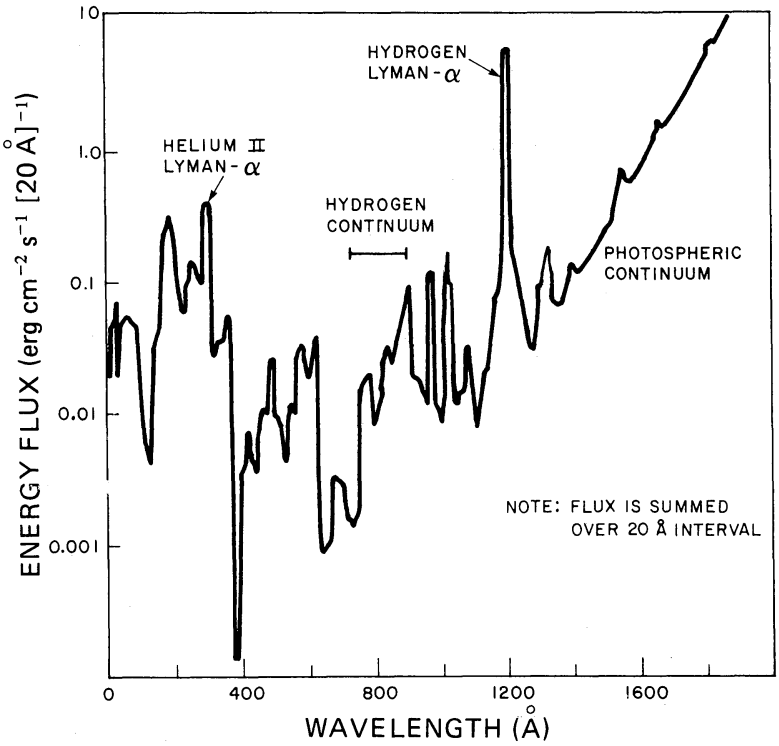
The solar spectral irradiance at 1 AU between 10 and 300 Å. Three states of solar activity are shown for the region 10–30 Å. The vertical extent of the shaded areas is representative of the variability of the spectral irradiance for changing solar conditions. (Adapted from Manson, J. E. in *The Solar Output and Its Variation*, O. R. White, ed., Colorado Associated University Press, Boulder, 1977.)



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The Sun *(cont.)*

Solar EUV flux distribution incident on Earth's atmosphere (moderately active, non-flaring sun). (Adapted from Carrigan, A. L. & Skrivanek, *Aerospace Environment*, Air Force Cambridge Research Laboratories, Massachusetts, 1974.)



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Solar System elemental abundances (normalized to Si = 10^6)

Element		Abundance	Element		Abundance	Element		Abundance
1	H	2.66×10^{10}	29	Cu	540	58	Ce	1.2
2	He	1.8×10^9	30	Zn	1260	59	Pr	0.18
3	Li	60	31	Ga	38	60	Nd	0.79
4	Be	1.2	32	Ge	117	62	Sm	0.24
5	B	9	33	As	6.2	63	Eu	0.094
6	C	1.11×10^7	34	Se	67	64	Gd	0.42
7	N	2.31×10^6	35	Br	9.2	65	Tb	0.076
8	O	1.84×10^7	36	Kr	41.3	66	Dy	0.37
9	F	780	37	Rb	6.1	67	Ho	0.092
10	Ne	2.6×10^6	38	Sr	22.9	68	Er	0.23
11	Na	6.0×10^4	39	Y	4.8	69	Tm	0.035
12	Mg	1.06×10^6	40	Zr	12	70	Yb	0.20
13	Al	8.5×10^4	41	Nb	0.9	71	Lu	0.035
14	Si	1.00×10^6	42	Mo	4.0	72	Hf	0.17
15	P	6500	44	Ru	1.9	73	Ta	0.020
16	S	5.0×10^5	45	Rh	0.40	74	W	0.15
17	Cl	4740	46	Pd	1.3	75	Re	0.051
18	Ar	1.06×10^5	47	Ag	0.46	76	Os	0.69
19	K	3500	48	Cd	1.55	77	Ir	0.72
20	Ca	6.25×10^4	49	In	0.19	78	Pt	1.41
21	Sc	31	50	Sn	3.7	79	Au	0.21
22	Ti	2400	51	Sb	0.31	80	Hg	0.42
23	V	254	52	Te	6.5	81	Tl	0.19
24	Cr	1.27×10^4	53	I	1.27	82	Pb	2.6
25	Mn	9300	54	Xe	5.84	83	Bi	0.14
26	Fe	9.0×10^5	55	Cs	0.39	90	Th	0.045
27	Co	2200	56	Ba	4.8	92	U	0.027
28	Ni	4.78×10^4	57	La	0.37			

The practical mass fractions of hydrogen, helium, and the heavier elements are: $X = 0.77$, $Y = 0.21$, $Z = 0.02$. (*Adapted from Cameron, A. G. W. in "Essays in Nuclear Astrophysics", Cambridge University Press*, 1981).

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The planets (physical elements)

Planet	Mass (Earth = 1)	Equatorial radius (Earth = 1)	Mean density ($g\,cm^{-3}$)	Equatorial surface gravity (Earth = 1)	Equatorial escape velocity ($km\,s^{-1}$)	Sidereal rotation period	Inclination of equator to orbit (°)	No. of satellites
Mercury	0.0558	0.382	5.42	0.387	4.3	58.65 d	0	0
Venus	0.8150	0.949	5.25	0.879	10.3	243.01 (retro) d	−2	0
Earth	1.0000	1.000	5.52	1.000	11.2	23.9345 h	23.45	1
Moon	0.012 30	0.2725	3.34	0.166	2.38	27.322 d	6.68	—
Mars	0.1074	0.532	3.94	0.380	5.0	24.6229 h	23.98	2
Jupiter	317.893	11.27	1.314	2.339	59.5	9.841 h	3.08	16
Saturn	95.147	9.44	0.69	0.925	35.6	10.233 h	29	17
Uranus	14.54	4.10	(1.19)	0.794	21.22	15.5 h	97.92	5
Neptune	17.23	3.88	1.66	1.125	23.6	15.8 h	28.8	2
Pluto	(0.0017)	(0.17)	(0.6–1.7)	(0.44)	(5.3)	6.3874 d	(≥ 50)	1

Values in parentheses are uncertain by more than 10%.
For the Earth: equatorial radius = 6378 km, mass = 5.976×10^{27} g,
equatorial surface gravity = 978 $cm\,s^{-2}$ (uncorrected for centrifugal force),
magnetic dipole moment = 8.00×10^{25} Gauss cm^3,
Earth–Moon mean distance = $3.844\,01 \times 10^5$ km.

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The planets (orbital elements)

Planet	Mean distance from Sun (AU)	Sidereal period (d)	Synodic period (d)	Mean orbital velocity ($km\ s^{-1}$)	Eccentricity	Inclination to the ecliptic (°)
Mercury	0.387 099	87.969	115.88	47.89	0.2056	7.00
Venus	0.723 332	224.701	583.92	35.03	0.0068	3.39
Earth	1.000 000	365.256	—	29.79	0.0167	—
Mars	1.523 691	686.980	779.94	24.13	0.0934	1.85
Jupiter	5.202 803	4 332.589	398.88	13.06	0.0485	1.30
Saturn	9.538 84	10 759.22	378.09	9.64	0.0556	2.49
Uranus	19.1819	30 685.4	369.66	6.81	0.0472	0.77
Neptune	30.0578	60 189.0	367.49	5.43	0.0086	1.77
Pluto	39.44	90 465.0	366.73	4.74	0.250	17.2

$1\ AU = 1.495\,979 \times 10^{13}$ cm. The sidereal period is the period of revolution measured with respect to the fixed stars; the synodic period is the interval between successive oppositions of a superior planet or successive inferior conjunctions of an inferior planet.

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Number	Name	Year found	Orbital radius (10^3 km)	Orbital period (d)	Eccentricity	Inclination (°)	Radius (km)	Magnitude† (m_v)
SATELLITE OF EARTH								
	Moon	—	384.4	27.322	0.055	5.1	1738	−12.7
SATELLITES OF MARS (2)								
MI	Phobos	1877	9.38	0.319	0.015	1.02	14 11 9	11.6
MII	Deimos	1877	23.46	1.262	0.001	1.82	(8) 6 (5)	12.7
SATELLITES OF JUPITER (16)								
(J16)	(Metis)	1979–80	127.96	0.295	(0)	(0)	(20)	17.4
(J15)	(Adrastea)	1979	128.98	0.298	(0)	(0)	12 10 8	18.9
JV	Amalthea	1892	181.3	0.498	0.003	0.45	135 85 75	14.1
JXIV	Thebe	1979–80	221.9	0.675	0.013	(0.9)	55 ? 45	(15.5)
JI	Io	1610	421.6	1.769	0.004	0.04	1815	5.0
JII	Europa	1610	670.9	3.551	0.009	0.47	1569	5.3
JIII	Ganymede	1610	1070	7.155	0.002	0.21	2631	4.6
JIV	Callisto	1610	1880	16.689	0.007	0.51	2400	5.6
JXIII	Leda	1974	11 094	238.7	0.148	26.1	(5)	20.2
JVI	Himalia	1904–05	11 480	250.6	0.158	27.6	(90)	14.8
JX	Lysithea	1938	11 720	259.2	0.107	29.0	(10)	18.4
JVII	Elara	1904–05	11 737	259.7	0.207	24.8	(40)	16.7
JXII	Ananke	1951	21 200	631	0.17	147	(10)	18.9
JXI	Carme	1938	22 600	692	0.21	164	(15)	18.0
JVIII	Pasiphae	1908	23 500	735	0.38	145	(20)	17.7
JIX	Sinope	1914	23 700	758	0.28	153	(15)	18.3

† At mean opposition.

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Natural satellites in the Solar System (*cont.*)

Number	Name	Year found	Orbital radius (10^3 km)	Orbital period (d)	Eccentricity	Inclination (°)	Radius (km)	Magnitude† (m_v)
SATELLITES OF SATURN (17)								
(SXV)	(Atlas)	1980	137.67	0.602	0.002	0.3	(19) ? (13)	18
1980 S 27		1980	139.35	0.613	0.004	0.0	70 (50) (37)	16.5
1980 S 26		1980	141.70	0.629	0.004	0.1	(55) (42) (33)	16
SX	Janus	1966	151.47	0.695	0.007	0.1	110 95 80	14.5
SXI	Epimetheus	1966	151.42	0.694	0.009	0.3	(70) (57) (50)	15.5
SI	Mimas	1789	185.54	0.942	0.020	1.52	196	12.9
SII	Enceladus	1789	238.04	1.370	0.004	0.02	250	11.8
SIII	Tethys	1684	294.67	1.888	0.000	1.86	530	10.3
SXIII	Telesto	1980	294.67	1.888	?	?	? (12) (11)	19
SXIV	Calypso	1980	294.67	1.888	?	?	(15) (12) (8)	18.5
SIV	Dione	1684	377.42	2.737	0.002	0.02	560	10.4
1980 S 6		1980	377.42	2.737	0.005	0.2	(18) ? (< 15)	18.5
SV	Rhea	1672	527.04	4.518	0.001	0.35	765	9.7
SVI	Titan	1655	1221.86	15.945	0.029	0.33	2575	8.4
SVII	Hyperion	1848	1481.1	21.277	0.104	0.43	175 117 (100)	14.2
SVIII	Iapetus	1671	3561.3	79.331	0.028	(7.52)	730	10.2–11.9
SIX	Phoebe	1898	12 954	550.4	0.163	175	110	16.5
SATELLITES OF URANUS (5)								
UV	Miranda	1948	129.4	1.414	0.027	4.22	(200)	16.5
UI	Ariel	1851	191.0	2.520	0.003	0.31	665	14.4
UII	Umbriel	1851	266.3	4.144	0.005	0.36	555	15.3
UIII	Titania	1787	435.9	8.706	0.002	0.14	800	14
UIV	Oberon	1787	583.5	13.463	0.001	0.10	815	14.2

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SATELLITES OF NEPTUNE (2)								
NI	Triton	1846	355.3	5.877	<0.001	159	(1750)	13.6
NII	Nereid	1949	5510	360.21	0.75	27.6	(200)	18.7
SATELLITE OF PLUTO								
PI	Charon	1978	19.7	6.387	(0)	(0)	(580)	17

† At mean opposition.

Parenthetic *names* and satellite *numbers* await approval by the International Astronomical Union. Parenthetic values are uncertain by at least 10%. *Inclinations* and *eccentricities* are the total values; 'forced' components are important for the eccentricities of the satellites Io, Europa, Enceladus, and Hyperion. Inclinations are with respect to planetary equators for inner satellites and to orbital planes for outer ones. Compound *radii* are the values for the 'best-fit' triaxial ellipsoid. *Magnitudes* are the visual mean opposition values.

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Short period comets

Comet name	Perihelion epoch	Perihelion longitude, $\bar{\omega}$ (°)	Longitude of ascending node, Ω (°)	Period, T_p (yr)	Semi-major axis of orbit, a (AU)	Eccentricity of orbit, e	Inclination of orbit, i (°)	Perihelion distance (AU)
Encke	1974.32	160.1	334.2	3.30	2.209	0.847	12.0	0.338
Temple 2	1972.87	310.2	119.3	5.26	3.024	0.549	12.5	1.364
Haneda-Campos	1978.77	12.016	131.7000	5.37	3.066	0.64152	5.805	1.099
Schwassmann-Wachmann 2	1974.70	123.3	126.0	6.51	3.489	0.386	3.7	2.142
Borrelly	1974.36	67.8	75.1	6.76	3.576	0.632	30.2	1.316
Whipple	1970.77	18.2	188.4	7.47	3.821	0.351	10.2	2.480
Oterma	1958.44	150.0	155.1	7.88	3.958	0.144	4.0	3.388
Schaumasse	1960.29	138.1	86.2	8.18	4.054	0.705	12.0	1.196
Comas Sola	1969.83	102.9	62.8	8.55	4.182	0.577	13.4	1.769
Schwassmann-Wachmann 1	1974.12	334.1	319.6	15.03	6.087	0.105	9.7	5.448
Neujmin 1	1966.94	334.0	347.2	17.93	6.858	0.775	15.0	1.543
Crommelin	1956.82	86.4	250.4	27.89	9.173	0.919	28.9	0.743
Olbers	1956.46	150.0	85.4	69.47	16.843	0.930	44.6	1.179
Pons-Brooks	1954.39	94.2	255.2	70.98	17.200	0.955	74.2	0.774
Halley	1986.112	170.0110	58.1540	76.0081	17.9435	0.9673	162.2384	0.587

(Adapted from Duffet-Smith, P., *Practical Astronomy with your Calculator*, Cambridge University Press.)

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Principal meteor streams

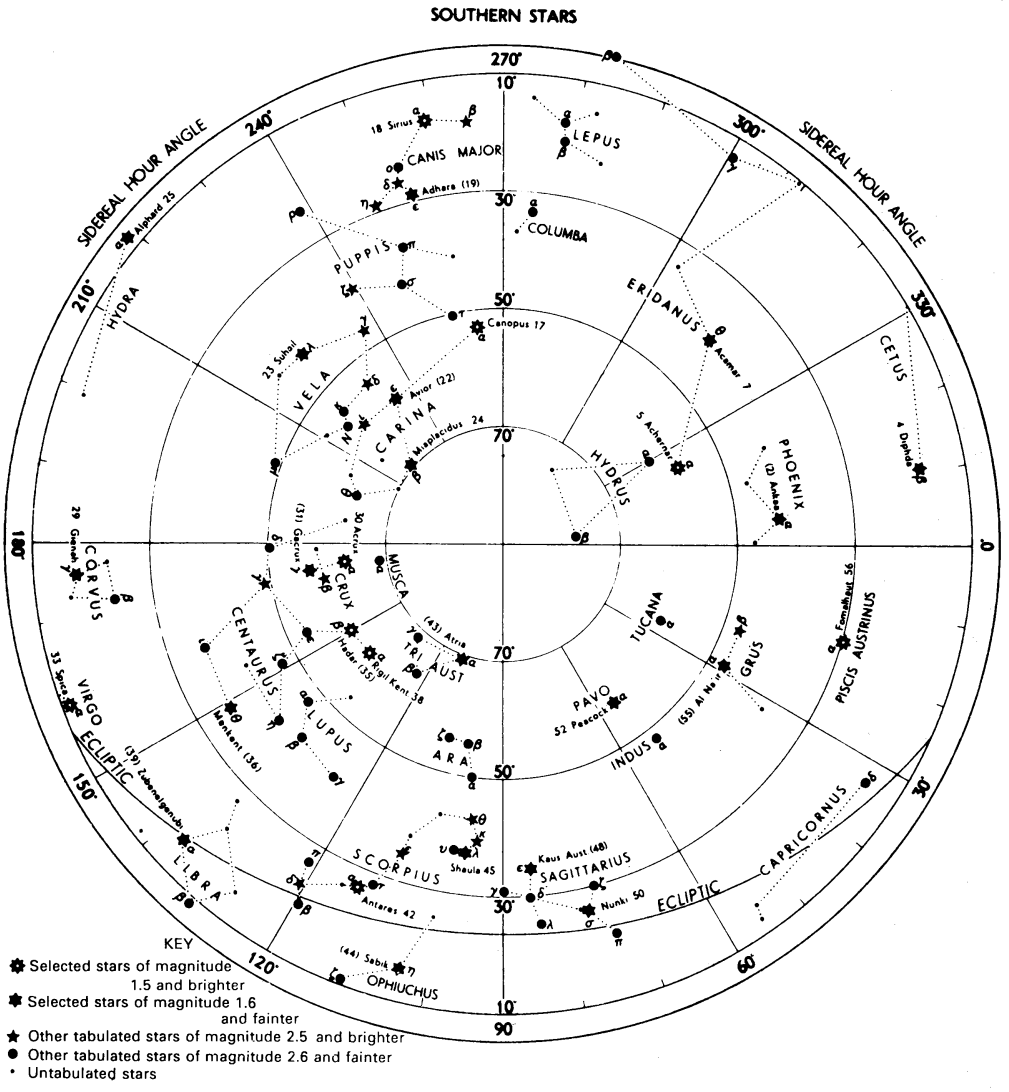
Stream	Maximum	Normal period of visibility	Radiant α	Radiant δ	Geocentric velocity km s^{-1}
Quadrantids	Jan. 3	Jan. 2–4	231°	+49°	43
Lyrids	Apr. 23	Apr. 20–22	271	+33	47
η Aquarids	May 4	May 2–7	336	0	64
δ Aquarids	July 30	July 20–Aug. 14	339	−10	41
Perseids	Aug. 12	July 29–Aug. 18	46	+58	60
Draconids	Oct. 10	Oct. 10	265	+54	24
Orionids	Oct. 21	Oct. 17–24	95	+15	66
Taurids	Nov. 4	Oct. 20–Nov. 25	55	+17	30
Leonids	Nov. 16	Nov. 14–19	153	+22	72
Andromedids	Nov. 20	Nov. 15–Dec. 6	13	+55	20
Geminids	Dec. 13	Dec. 8–15	112	+32	36
Ursids	Dec. 22	Dec. 19–23	213	+76	36
		Permanent daytime streams			
Arietids	June 8	May 29–June 17	44	+23	39
ξ Perseids	June 9	June 1–15	61	+23	29
β Taurids	June 30	June 23–July 7	86	+19	31

(Adapted from Allen, C. W., *Astrophysical Quantities*, The Athlone Press, 1973.)

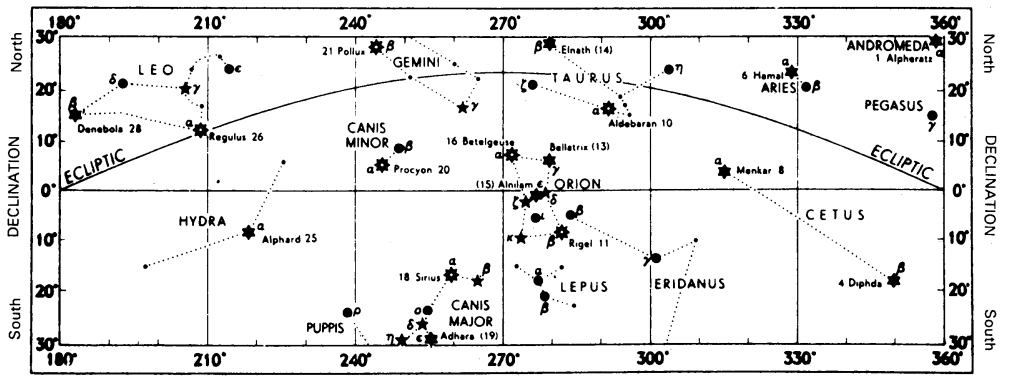
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Stars

Star charts



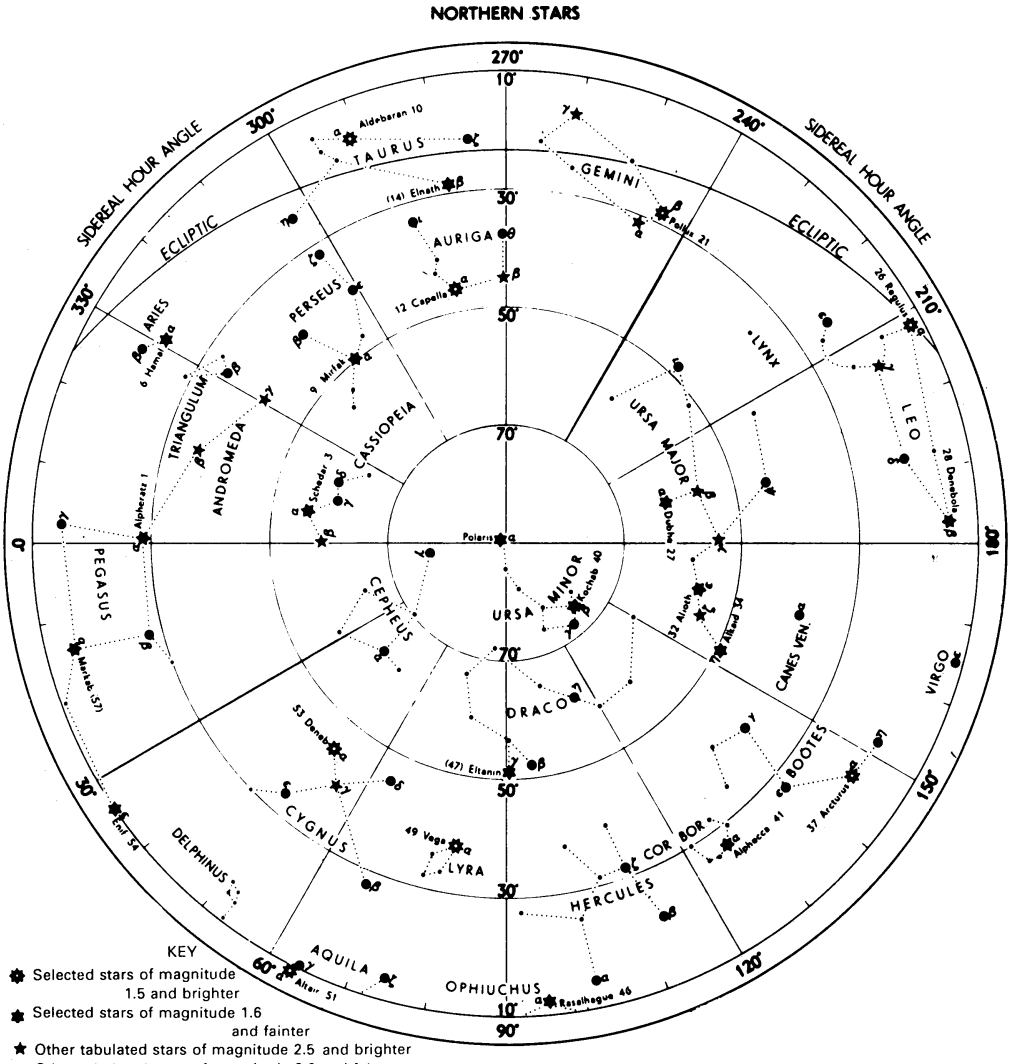
EQUATORIAL STARS S.H.A. (180° TO 360°)



SIDEREAL HOUR ANGLE

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Star charts *(cont.)*



(Adapted from *The Nautical Almanac*)

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Constellation	Gen. ending	Contr.	Description	α	δ	Area[a] (sq. deg.)	Order of size
Andromeda	-dae	And	the chained maiden[b]	1^h	40°N	722.278	19
Antlia	-liae	Ant	the air pump	10	35 S	238.901	62
Apus	-podis	Aps	the bird of paradise	16	75 S	206.327	67
Aquarius	-rii	Aqr	the water pourer	23	15 S	979.854	10
Aquila	-lae	Aql	the eagle	20	5 N	652.473	22
Ara	-rae	Ara	the altar	17	55 S	237.057	63
Aries	-ietis	Ari	the ram	3	20 N	441.395	39
Auriga	-gae	Aur	the wagoner	6	40 N	657.438	21
Boötes	-tis	Boo	the ploughman	15	30 N	906.831	13
Caelum	-aeli	Cae	the burin	5	40 S	124.865	81
Camelopardalis	-di	Cam	the giraffe	6	70 N	756.828	18
Cancer	-cri	Cnc	the crab	9	20 N	505.872	31
Canes Venatici	-num -corum	CVn	the hunting dogs	13	40 N	465.194	38
Canis Major	-is -ris	CMa	the large dog	7	20 S	380.118	43
Canis Minor	-is -ris	CMi	the small dog	8	5 N	183.367	71
Capricornus	-ni	Cap	the goat	21	20 S	413.947	40
Carina	-nae	Car	the keel	9	60 S	494.184	34
Cassiopeia	-peiae	Cas	Cassiopeia	1	60 N	598.407	25
Centaurus	-ri	Cen	the centaur	13	50 S	1060.422	9
Cepheus	-phei	Cep	King Cepheus	22	70 N	587.787	27
Cetus	-ti	Cet	the sea monster	2	10 S	1231.411	4
Chamaeleon	-ntis	Cha	the chamaeleon	11	80 S	131.592	79
Circinus	-ni	Cir	the pair of compasses	15	60 S	93.353	85
Columba	-bae	Col	the dove	6	35 S	270.184	54
Coma Berenices	-mae -cis	Com	the hair of Berenice	13	20 N	386.475	42

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Corona Australis	-nae -lis	CrA	the southern crown	19	40 S	127.696	80
Corona Borealis	-nae -lis	CrB	the northern crown	16	30 N	178.710	73
Corvus	-vi	Crv	the crow	12	20 S	183.801	70
Crater	-eris	Crt	the cup	11	15 S	282.398	53
Crux	-ucis	Cru	the southern cross	12	60 S	68.447	88
Cygnus	-gni	Cyg	the swan	21	40 N	803.983	16
Delphinus	-ni	Del	the dolphin	21	10 N	188.549	69
Dorado	-dus	Dor	the swordfish	5	65 S	179.173	72
Draco	-onis	Dra	the dragon	17	65 N	1082.952	8
Equuleus	-lei	Equ	the foal	21	10 N	71.641	87
Eridanus	-ni	Eri	the river	3	20 S	1137.919	6
Fornax	-acis	For	the furnace	3	30 S	397.502	41
Gemini	-norum	Gem	the twins	7	20 N	513.761	30
Grus	-ruis	Gru	the crane	22	45 S	365.513	45
Hercules	-lis	Her	Hercules	17	30 N	1225.148	5
Horologium	-gii	Hor	the clock	3	60 S	248.885	58
Hydra	-drae	Hya	the water snake	10	20 S	1302.844	1
Hydrus	-dri	Hyi	the sea serpent	2	75 S	243.035	61
Indus	-di	Ind	the Indian	21	55 S	294.006	49
Lacerta	-tae	Lac	the lizard	22	45 N	200.688	68
Leo	-onis	Leo	the lion	11	15 N	946.964	12
Leo Minor	-onis -ris	LMi	the small lion	10	35 N	231.956	64
Lepus	-poris	Lep	the hare	6	20 S	290.291	51
Libra	-rae	Lib	the balance	15	15 S	538.052	29
Lupus	-pi	Lup	the wolf	15	45 S	333.683	46
Lynx	-ncis	Lyn	the lynx	8	45 N	545.386	28
Lyra	-rae	Lyr	the lyre	19	40 N	286.476	52
Mensa	-sae	Men	the table[c]	5	80 S	153.484	75
Microscopium	-pii	Mic	the microscope	21	35 S	209.513	66
Monoceros	-rotis	Mon	the unicorn	7	5 S	481.569	35

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Constellations (*cont.*)

Constellation	Gen. ending	Contr.	Description	α	δ	Area[a] (sq. deg.)	Order of size
Musca	-cae	Mus	the fly	12°	70°S	138.355	77
Norma	-mae	Nor	the square	16	50 S	165.290	74
Octans	-ntis	Oct	the octant	22	85 S	291.045	50
Ophiuchus	-chi	Oph	the serpent bearer	17	0	948.340	11
Orion	-nis	Ori	the hunter	5	5 N	594.120	26
Pavo	-vonis	Pav	the peacock	20	65 S	377.666	44
Pegasus	-si	Peg	the winged horse	22	20 N	1120.794	7
Perseus	-sei	Per	Perseus	3	45 N	614.997	24
Phoenix	-nisis	Phe	the Phoenix	1	50 S	469.319	37
Pictor	-ris	Pic	the easel	6	55 S	246.739	59
Pisces	-cium	Psc	the fishes	1	15 N	889.417	14
Piscis Austrinus	-is -ni	PsA	the southern fish	22	30 S	245.375	60
Puppis	-ppis	Pup	the poop	8	40 S	673.434	20
Pyxis (= Malus)	-xidis	Pyx	the compass	9	30 S	220.833	65
Reticulum	-li	Ret	the net	4	60 S	113.936	82
Sagitta	-tae	Sge	the arrow	20	10 N	79.923	86
Sagittarius	-rii	Sgr	the archer	19	25 S	867.432	15
Scorpius	-pii	Sco	the scorpion	17	40 S	496.783	33
Sculptor	-ris	Scl	the sculptor	0	30 S	474.764	36
Scutum	-ti	Sct	the shield[d]	19	10 S	109.114	84
Serpens (Caput and Cauda)	-ntis	Ser	the serpent	18	5 S	636.928	23
Sextans	-ntis	Sex	the sextant	10	0	313.515	47
Taurus	-ri	Tau	the bull	4	15 N	797.249	17
Telescopium	-pii	Tel	the telescope	19	50 S	251.512	57
Triangulum	-li	Tri	the triangle	2	30 N	131.847	78

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Triangulum Australe	-li -lis	TrA	the southern triangle	16	65 S	109.978	83
Tucana	-nae	Tuc	the toucan	0	65 S	294.557	48
Ursa Major	-sae -ris	UMa	the great bear	11	50 N	1279.660	3
Ursa Minor	-sae -ris	UMi	the little bear	15	70 N	255.864	56
Vela	-lorum	Vel	the sails	9	50 S	499.649	32
Virgo	-ginis	Vir	the virgin	13	0	1294.428	2
Volans	-ntis	Vol	the flying fish	8	70 S	141.354	76
Vulpecula	-lae	Vul	the little fox	20	25 N	268.165	55

[a] From *Sky and Telescope*, June 1983.
[b] Daughter of Cepheus and Cassiopeia.
[c] After Table Mountain in South Africa.
[d] Of John Sobieski, the Polish hero.

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The brightest stars in the sky (limiting magnitude, $V = 1.35$)

Rank	Name	Designation	V magnitude	α 2000	δ 2000
1	Sirius	α Canis Majoris	−1.46	$6^h 45^m 8.9^s$	−16° 42′ 58″
2	Canopus	α Carinae	−0.72	6 23 57.1	−52 41 44
3	Rigil Kentaurus	α Centauri	−0.27	14 39 36.7	−60 50 02
4	Arcturus	α Boötis	−0.04	14 15 39.6	+19 10 57
5	Vega	α Lyrae	+0.03	18 36 56.2	+38 47 01
6	Capella	α Aurigae	+0.08	5 16 41.3	+45 59 53
7	Rigel	β Orionis	+0.12	5 14 32.2	−8 12 06
8	Procyon	α Canis Minoris	+0.38	7 39 18.1	+5 13 30
9	Achernar	α Eridani	+0.46	1 37 42.9	−57 14 12
10	Betelgeuse	α Orionis	+0.50 (var)	5 55 10.2	+7 24 26
11	Hadar	β Centauri	+0.61	14 03 49.4	−60 22 22
12	Altair	α Aquilae	+0.77	19 50 46.8	+8 52 06
13	Aldebaran	α Tauri	+0.85 (var)	4 35 55.2	+16 30 33
14	Acrux	α Crucis	+0.87	12 26 35.9	−63 05 56
15	Antares	α Scorpii	+0.96 (var)	16 29 24.3	−26 25 55
16	Spica	α Virginis	+0.98	13 25 11.5	−11 09 41
17	Pollux	β Geminorum	+1.14	7 45 18.9	+28 01 34
18	Fomalhaut	α Piscis Austrini	+1.16	22 57 38.9	−29 37 20
19	Deneb	α Cygni	+1.25	20 41 25.8	+45 16 49
20	Mimosa	β Crucis	+1.25	12 47 43.2	−59 41 19
21	Regulus	α Leonis	+1.35	10 08 22.2	+11 58 02

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The 100 visually brightest stars (limiting magnitude, $V = 2.59$)

Star name*	α 2000	δ 2000	μ(α)	μ(δ)	V	$B-V$	M_v	Spec	RV (km s^{-1})	d (pc)	Notes
21 α And	0^{h}08^{m}23^s.2	+29°05′26″	+0^s.010	−0″.16	2.06	−0.11	0.3	A0 p	−12	22 mn	Alpheratz, m
11 β Cas	0 09 10.6	+59 08 59	+0.068	−0.18	2.27	0.34	1.7	F2 IV	+12	13 ts	Caph, m
α Phe	0 26 17.0	−42 18 22	+0.019	−0.39	2.39	1.09	0.5	K0 III	+75	24 s	(Ankaa), m
18 α Cas	0 40 30.4	+56 32 15	+0.006	−0.03	2.23	1.17	−0.6	K0 II–III	−4	37 s	Schedar, m
16 β Cet	0 43 35.3	−17 59 12	+0.016	+0.04	2.04	1.02	0.4	K0 III	+13	21 ts	Deneb Kait, Diphda
27 γ Cas	0 56 42.4	+60 43 00	+0.003	0.00	2.47	−0.15	−4.4	B0 IV e	−7	240 s	Cih, m, v
43 β And	1 09 43.8	+35 37 14	+0.015	−0.11	2.06	1.58	−0.1	M0 III	0	27 ts	Mirach, m
α Eri	1 37 42.9	−57 14 12	+0.013	−0.03	0.46	−0.16	−1.6	B5 IV	+19	26 s	Achernar
57 γ^1 And	2 03 53.9	+42 19 47	+0.004	−0.05	2.18	1.20	−0.7	K2 III	−12	37 mn	Almach
57 γ^2 And	2 03 54.7	+42 19 51	+0.003	−0.05	5.03			A0 p	−14	37 mn	m
13 α Ari	2 07 10.3	+23 27 45	+0.014	−0.14	2.00	1.15	−0.1	K2 III	−14	26 ts	Hamal
68 *o* Cet	2 19 20.6	−2 58 39	−0.001	−0.23	2.0	1.7	−0.3	Md	+64	29 mn	Mira, m, v
1 α UMi	2 31 50.4	+89 15 51	+0.232	−0.01	2.02	0.60	−4.6	F8 Ib	−17		Polaris, m
92 α Cet	3 02 16.7	+4 05 23	−0.001	−0.07	2.53	1.64	−0.5	M2 III	−26	40 mn	Menkar
26 β Per	3 08 10.1	+40 57 21	0.000	0.00	2.12	−0.05	−0.2	B8 V	+4	29 ts	Algol, m, v
33 α Per	3 24 19.3	+49 51 40	+0.003	−0.02	1.80	0.48	−4.6	F5 Ib	−2	190 s	Mirfak, m
87 α Tau	4 35 55.2	+16 30 33	+0.005	−0.19	0.85	1.54	−0.8	K5 III	+54	21 ts	Aldebaran, m
13 α Aur	5 16 41.3	+45 59 53	+0.008	−0.42	0.08	0.80	−0.5	G8 III	+30	13 t	Capella, m
19 β Ori	5 14 32.2	−8 12 06	0.000	0.00	0.12	−0.03	−7.1	B8 Ia	+21	280 s	Rigel, m
24 γ Ori	5 25 07.8	+6 20 59	−0.001	−0.01	1.64	−0.22	−3.6	B2 III	+18	110 s	Bellatrix, m
112 β Tau	5 26 17.5	+28 36 27	+0.002	−0.17	1.65	−0.13	−1.4	B7 III	+8	40 mx	El Nath, m
34 δ Ori	5 32 00.3	−0 17 57	0.000	0.00	2.23	−0.22		O9.5 II	+16		Mintaka, m
11 α Lep	5 32 43.7	−17 49 20	0.000	0.00	2.58	0.21	−4.7	F0 Ib	+25	290 s	Arneb, m

* See page 49 for explanation of column headings.

The 100 visually brightest stars (*cont.*)

Star name*	α 2000	δ 2000	μ(α)	μ(δ)	*V*	*B* − *V*	M_v	Spec	*RV* (km s^{-1})	*d* (pc)	Notes
46 ε Ori	$5^h36^m12^s.7$	−1° 12′ 07″	0^s.000	0″.00	1.70	−0.19	−6.1	B0 Ia	+26	370 s	Alnilam, m
50 ζ Ori	5 40 45.5	−1 56 34	0.000	0.00	1.77	−0.21	−5.9	O9.5 Ib	+18	340 s	Alnitak, m
53 κ Ori	5 47 45.3	−9 40 11	0.000	−0.01	2.06	−0.17	−6.7	B0.5 Ia	+21	560 s	Saiph
58 α Ori	5 55 10.2	+7 24 26	+0.002	+0.01	0.50	1.85	−6.0	M2 Iab	+21	200 s	Betelgeuse, m
34 β Aur	5 59 31.7	+44 56 51	−0.005	0.00	1.90	0.03	0.2	A2 IV	−18	22 ts	Menkalinan, m
2 β CMa	6 22 41.9	−17 57 22	−0.001	0.00	1.98	−0.23	−4.7	B1 II–III	+34	220 s	Mirzam, m
α Car	6 23 57.1	−52 41 44	+0.003	+0.02	−0.72	0.15	−8.5	F0 Ia	+21	360 s	Canopus
24 γ Gem	6 37 42.7	+16 23 57	+0.003	−0.04	1.93	0.00	−0.1	A0 IV	−13	26 ts	Alhena, m
9 α CMa	6 45 08.9	−16 42 58	−0.038	−1.21	−1.46	0.01	1.4	A1 V	−8	2.7 t	Sirius, m
21 ε CMa	6 58 37.5	−28 58 20	0.000	0.00	1.50	−0.21	−4.4	B2 II	+27	150 s	Adhara, m
25 δ CMa	7 08 23.4	−26 23 36	−0.001	0.00	1.86	0.65	−8.0	F8 Ia	+34	940 s	Wezen
31 η CMa	7 24 05.6	−29 18 11	−0.001	0.00	2.44	−0.07	−7.0	B5 Ia	+41	760 s	Aludra, m
66 α Gem	7 34 35.9	+31 53 18	−0.013	−0.10	1.58	0.04	0.8	A1 V	+4	14 ts	Castor, m
10 α CMi	7 39 18.1	+5 13 30	−0.047	−1.03	0.38	0.42	2.7	F5 IV	−3	3.5 t	Procyon, m
78 β Gem	7 45 18.9	+28 01 34	−0.047	−0.05	1.14	1.00	0.9	K0 III	+3	11 ts	Pollux, m
ζ Pup	8 03 35.0	−40 00 12	−0.003	+0.01	2.25	−0.26		O5.8	−24		Naos
γ Vel	8 09 31.9	−47 20 12	−0.001	0.00	1.78	−0.22		WC7	+35		m
ε Car	8 22 30.8	−59 30 34	−0.003	+0.01	1.86	1.27	−2.1	K0 II	+12	63 s	(Avior)
δ Vel	8 44 42.2	−54 42 30	+0.003	−0.08	1.96	0.04	0.3	A0 V	+2	21 ts	m
λ Vel	9 07 59.7	−43 25 57	−0.002	+0.01	2.21	1.66	−3.7	K5 Ib	+18	150 ts	Suhail
β Car	9 13 12.2	−69 43 02	−0.029	+0.10	1.68	0.00	−0.4	A0 III	−5	26 s	Miaplacidus
ι Car	9 17 05.4	−59 16 31	−0.002	0.00	2.25	0.18	−4.7	F0 Ib	+13	250 s	Aspidiske, Scutulum
κ Vel	9 22 06.8	−55 00 38	−0.001	+0.01	2.50	−0.18	−2.9	B2 IV	+22	120 s	m
30 α Hya	9 27 35.2	−8 39 31	−0.001	+0.03	1.98	1.44	−0.1	K3 III	−4	26 mn	Alphard

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32 α Leo	10 08 22.2	+11 58 02	−0.017	0.00	1.35	−0.11	−0.7	B7 V	+4	26 ts	Regulus, m
41 γ^1 Leo	10 19 58.3	+19 50 30	+0.022	−0.15	2.28	1.08	0.2	K0 III	−37		Algieba, m
41 γ^2 Leo	10 19 58.6	+19 50 25	+0.022	−0.17	3.58			G7 III	−36		m
48 β UMa	11 01 50.4	+56 22 56	+0.010	+0.03	2.37	−0.02	1.0	A1 V	−12	19 ts	Merak
50 α UMa	11 03 43.6	+61 45 03	−0.017	−0.07	1.79	1.07	0.0	K0 III	−9	23 ts	Dubhe, m
68 δ Leo	11 14 06.4	+20 31 25	+0.010	−0.14	2.56	0.12	1.5	A4 V	−21	16 ts	Zosma, m
94 β Leo	11 49 03.5	+14 34 19	−0.034	−0.12	2.14	0.09	1.7	A3 V	0	12 mx	Denebolan, m
64 γ UMa	11 53 49.7	+53 41 41	+0.011	+0.01	2.44	0.00	0.6	A0 V	−13	23 s	Phecda
4 γ Crv	12 15 48.3	−17 32 31	−0.011	+0.02	2.59	−0.11	−1.2	B8 III	−4	57 s	Gienah
α^1 Cru	12 26 35.9	−63 05 56	−0.004	−0.02	1.41	0.1	−3.8	B1 IV	−11	110 s	Acrux, m
α^2 Cru	12 26 36.5	−62 05 58	−0.005	−0.02	1.88		−3.3	B3 n	−1	110 s	m
γ Cru	12 31 09.9	−57 06 47	+0.003	−0.27	1.63	1.59	−0.5	M3 III	+21	27 s	(Gacrux), m
γ Cen	12 41 30.9	−48 57 34	−0.019	−0.01	2.17	−0.01	−0.5	A0 III	−8	34 s	Muhlifain, m
β Cru	12 47 43.2	−59 41 19	−0.005	−0.02	1.25	−0.23	−4.3	B0 III	+20	130 mx	Mimosa
77 ε UMa	12 54 01.7	+55 57 35	+0.013	−0.01	1.77	−0.02	0.4	A0 p	−9	19 mn	Alioth
79 ζ UMa	13 23 55.5	+54 55 31	+0.014	−0.02	2.27	0.02	1.0	A2 V	−9	18 ts	Mizar, m
67 α Vir	13 25 11.5	−11 09 41	−0.003	−0.03	0.98	−0.23	−3.5	B1 V	+1	79 s	Spica, m, v
ε Cen	13 39 53.2	−53 27 58	−0.002	−0.02	2.30	−0.22	−3.6	B1 V	+6	150 s	m
85 η UMa	13 47 32.3	+49 18 48	−0.013	−0.01	1.86	−0.19	−0.7	B3 V	−11	33 mx	Alkaid
ζ Cen	13 55 32.3	−47 17 17	−0.006	−0.04	2.55	−0.22	−2.7	B2 IV	+7	110 mx	m
β Cen	14 03 49.4	−60 22 22	−0.003	−0.02	0.61	−0.24	−5.1	B1 II		140 s	Hadar, m
5 θ Cen	14 06 40.9	−36 22 12	−0.043	−0.52	2.06	1.01	1.3	K0 III–IV	+1	14 ts	(Menkent)
16 α Boo	14 15 39.6	+19 10 57	−0.077	−2.00	−0.04	1.23	−0.2	K2 III p	−5	11 t	Arcturus
η Cen	14 35 30.3	−42 09 28	−0.003	−0.04	2.31	−0.19	−2.9	B3 III	0	110 s	
α^2 Cen	14 39 35.4	−60 50 13	−0.494	+0.69	1.39		5.8	K1 V	−21	1.3 t	m
α^1 Cen	14 39 36.7	−60 50 02	−0.494	+0.69	0.00	0.68	4.4	G2 V	−25	1.3 t	Rigil Kent, m
α Lup	14 41 55.7	−47 23 17	−0.002	−0.02	2.30	−0.20	−4.3	B1 III	+7	210 s	m
36 ε Boo	14 44 59.1	+27 04 27	−0.004	+0.02	2.37	0.97	−0.9	K0 II–III	−17	46 s	Izar
7 β UMi	14 50 42.2	+74 09 19	−0.009	+0.01	2.08	1.47	−0.2	K4 III	+17	29 ts	Kochab

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The 100 visually brightest stars (*cont.*)

Star name	α 2000	δ 2000	μ(α)	μ(δ)	V	B − V	M_v	Spec	RV (km s^{-1})	d (pc)	Notes
5 α CrB	15^{h}34^{m}41^s.2	+26°42′53″	+0^s.009	−0″.09	2.23	−0.02	0.3	A0 V	+2	24 ts	Alphecca, m
7 δ Sco	16 00 19.9	−22 37 18	−0.001	−0.03	2.32	−0.12	−3.8	B0 V	−14	170 s	Dzuba
8 β^1 Sco	16 05 26.1	−19 48 19	0.000	−0.02	2.64	−0.07	−4.3	B0.5 V	−7	250 s	Acrab, m
8 β^2 Sco	16 05 26.4	−19 48 07	−0.001	−0.02	4.92	−0.02	−2.5	B2 V	−5	250 s	
21 α Sco	16 29 24.3	−26 25 55	0.000	−0.02	0.96	1.83	−4.0	M1 Ib	−3	100 s	Antares, m, v
13 ζ Oph	16 37 09.4	−10 34 02	+0.001	+0.02	2.56	0.02	−3.6	O9.5 V	−19	170 s	
α TrA	16 48 39.8	−69 01 39	+0.005	−0.03	1.92	1.44	0.8	K2 III	−4	17 s	(Atria)
26 ε Sco	16 50 09.7	−34 17 36	−0.049	−0.25	2.29	1.15	0.8	K2 III	−3	20 mx	
35 η Oph	17 10 22.5	−15 43 30	+0.003	+0.09	2.43	0.06	1.2	A2 V	−1	18 ts	Sabik, m
35 λ Sco	17 33 36.4	−37 06 14	0.000	−0.03	1.63	−0.22	−3.0	B2 IV	0	84 s	Shaula, m
55 α Oph	17 34 55.9	+12 33 36	+0.008	−0.23	2.08	0.15	0.7	A5 III	+13	19 ts	Ras-Alhague
θ Sco	17 37 19.0	−42 59 52	+0.001	0.00	1.87	0.40	−5.4	F0 I–II	+1	280 s	
κ Sco	17 42 29.0	−39 01 48	−0.001	−0.03	2.41	−0.22	−3.0	B2 IV	−10	120 s	
33 γ Dra	17 56 36.2	+51 29 20	−0.001	−0.02	2.23	1.52	−0.2	K5 III	−28	31 s	Eltanin, m
20 ε Sgr	18 24 10.2	−34 23 05	−0.003	−0.13	1.85	−0.03	−0.2	B9 IV	−11	26 s	Kaus Australis, m
3 α Lyr	18 36 56.2	+38 47 01	+0.017	+0.28	0.03	0.00	0.5	A0 V	−14	8.1 t	Vega, m
34 σ Sgr	18 55 15.7	−26 17 48	+0.001	−0.05	2.02	−0.22	−2.0	B3 IV–V	−11	64 s	Nunki, m
53 α Aql	19 50 46.8	+8 52 06	+0.036	+0.39	0.77	0.22	2.2	A7 IV–V	−26	5.1 t	Altair, m
37 γ Cyg	20 22 13.5	+40 15 24	0.000	0.00	2.20	0.68	−4.6	F8 Ib	−8	230 s	Sadir, m
α Pav	20 25 38.7	−56 44 06	+0.002	−0.08	1.94	−0.20	−2.3	B3 IV	+2	71 s	(Peacock), m
50 α Cyg	20 41 25.8	+45 16 49	0.000	+0.01	1.25	0.09	−7.5	A2 Ia	−5	560 s	Deneb, m
53 ε Cyg	20 46 12.5	+33 58 13	+0.028	+0.33	2.46	1.03	0.5	K0 III	−10	25 ts	Gienar, m
5 α Cep	21 18 34.6	+62 35 08	+0.022	+0.05	2.44	0.22	1.7	A7 IV–V	−10	14 ts	Alderamin, m
8 ε Peg	21 44 11.0	+9 52 30	+0.002	0.00	2.38	1.52	−3.6	K2 Ib	+5	160 s	Enif, m

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α Gru	22 08 13.8	−46 57 40	+0.013	−0.15	1.74	−0.13	0.1	B5 V	+12	21 mx	(Al Na'ir), m
β Gru	22 42 39.9	−46 53 05	+0.014	−0.01	2.11	1.62	−1.5	M3 II	+2	53 mx	
24 α PsA	22 57 38.9	−29 37 20	+0.026	−0.16	1.16	0.09	2.0	A3 V	+7	6.7 t	Fomalhaut
53 β Peg	23 03 46.3	+28 04 58	+0.014	+0.14	2.42	1.67	−1.2	M2 II–III	+9	54 s	Scheat, m, v
54 α Peg	23 04 45.5	+15 12 19	+0.004	−0.04	2.49	−0.04	0.0	B9 V	−4	31 ts	Markab

Column headings

Star name: the Flamsteed number, Bayer letter, and constellation abbreviation.

α 2000: right ascension for equator, equinox, and epoch 2000.0.

δ 2000: declination for equator, equinox, and epoch 2000.0.

$\mu(\alpha)$: proper motion in right ascension in seconds of time per year.

$\mu(\delta)$: proper motion in declination in seconds of arc per year.

V: visual magnitude in the standard U, B, V photometric system.

$B-V$: the color index in the U, B, V system.

M_v: the absolute visual magnitude ($M_v = V + 5 - 5\log d$ (pc)).

Spec: the spectral type and luminosity class in the MKK system.

RV: radial velocity. Positive means receding from the Solar System.

d (pc): distance to the star in parsecs. 't' denotes the distance is based on a trigonometric parallax; 's' denotes spectroscopic parallax; 'mn' denotes a minimum likely value; 'mx' denotes a maximum likely value.

Notes: the classical names are given here; 'm' means the star is part of a multiple system; 'v' means the star is variable. Only the dominant star is listed. If more than one member of a multiple system is visually bright, all the visually bright members are listed ($V < 8.0$). The combined magnitude of a pair of close stars is given by:

$$m = m_2 - 2.5\log(R+1)$$ where $R = 10^{0.4(m_2 - m_1)}$, m_1 is the magnitude of the brightest component, and m_2 is that of the fainter star.

(Data are from *Sky Catalogue 2000.00*, Hirshfeld, A. & Sinnott, R., eds., Sky Publishing Corp., 1982.)

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Stars within 5 pc

No.	Name	α 1950	δ 1950	Trig. parallax, π	Proper motion, μ″ yr⁻¹	Radial velocity v_r km s⁻¹	Spec	V	$B-V$	$U-B$	$R-I$	M_v	Luminosity ($L_\odot = 1$)
1	Sun						G2 V	−26.72	0.65	0.10		4.85	1.0
2	Proxima Cen	14h 26m.3	−62° 28′	0″.772 ± 0″.007	3.85	−16	dM5 e	11.05	1.97		1.65	15.49	0.000 06
	α Cen A	14 36.2	−60 38	0.750 ± 0.010	3.68	−22	G2 V	−0.01	0.68		0.22	4.37	1.6
	α Cen B						K0 V	1.33	0.88		0.24	5.71	0.45
3	Barnard's star	17 55.4	+4 33	0.545 ± 0.003	10.31	−108	M5 V	9.54	1.74	1.29	1.25	13.22	0.000 45
4	Wolf 359	10 54.1	+7 19	0.421 ± 0.006	4.70	+13	dM8 e	13.53	2.01	1.54	1.85	16.65	0.000 02
5	BD+36°2147	11 00.6	+36 18	0.397 ± 0.004	4.78	−84	M2 V	7.50	1.51	1.12	0.91	10.50	0.0055
6	L 726−8=A	1 36.4	−18 13	0.387 ± 0.012	3.36	+29	dM6 e	12.52	1.85	1.09:	1.6	15.46	0.000 06
	UV Cet=B					+32	dM6 e	13.02				15.96	0.000 04
7	Sirius A	6 42.9	−16 39	0.377 ± 0.006	1.33	−8	A1 V	−1.46	0.00	−0.04	0.12	1.42	23.5
	Sirius B						DA	8.3:	−0.12:	−1.03:		11.2	0.003
8	Ross 154	18 46.7	−23 53	0.345 ± 0.012	0.72	−4	dM5 e	10.45	1.70	1.17	1.30	13.14	0.000 48
9	Ross 248	23 39.4	+43 55	0.314 ± 0.004	1.60	−81	dM6 e	12.29	1.91	1.48	1.56	14.78	0.000 11
10	ε Eri	3 30.6	−9 38	0.303 ± 0.004	0.98	+16	K2 V	3.73	0.88	0.58	0.30	6.14	0.30
11	Ross 128	11 45.1	+1 06	0.298 ± 0.006	1.38	−13	dM5	11.10	1.76	1.30	1.30	13.47	0.000 36
12	61 Cyg A	21 04.7	+38 30	0.294 ± 0.006	5.22	−64	K5 V	5.22	1.17	1.11	0.47	7.56	0.082
	61 Cyg B						K7 V	6.03	1.37	1.23	0.60	8.37	0.039
13	ε Ind	21 59.6	−57 00	0.291 ± 0.010	4.70	−40	K5 V	4.68	1.05	1.00	0.40	7.00	0.14
14	BD+43°44A	0 15.5	+43 44	0.290 ± 0.006	2.90	+13	M1 V	8.08	1.56	1.24	0.88	10.39	0.0061
	+43 44B					+20	M6 V e	11.06	1.80	1.40	1.22	13.37	0.000 39
15	L 789−6	22 35.7	−15 36	0.290 ± 0.007	3.26	−60	dM7 e	12.18	1.96	1.54	1.66	14.49	0.000 14
16	Procyon A	7 36.7	+5 21	0.285 ± 0.006	1.25	−3	F5 IV–V	0.37	0.42	0.03	0.14	2.64	7.65
	Procyon B						DF	10.7				13.0	0.000 55
17	BD+59°1915A	18 42.2	+59 33	0.282 ± 0.004	2.29	0	dM4	8.90	1.54	1.11	1.07	11.15	0.0030
	+59 1915B				2.27	+10	dM5	9.69	1.59	1.14	1.14	11.94	0.0015
18	CD−36°15693	23 02.6	−36 09	0.279 ± 0.024	6.90	+10	M2 V	7.35	1.48	1.18	0.85	9.58	0.013
19	G 51−15	8 26.9	+26 57	0.278 ± 0.004	1.27			14.81	2.06		1.79	17.03	0.000 01
20	τ Cet	1 41.7	−16 12	0.277 ± 0.007	1.92	−16	G8 V	3.50	0.72	0.22	0.26	5.72	0.45
21	BD+5°1668	7 24.7	+5 23	0.266 ± 0.006	3.77	+26	dM5	9.82	1.56	1.12	1.19	11.94	0.0015
22	L 725−32	1 09.9	−17 16	0.261 ± 0.012	1.32	+28	dM5 e	12.04	1.83	1.46	1.44	14.12	0.000 20

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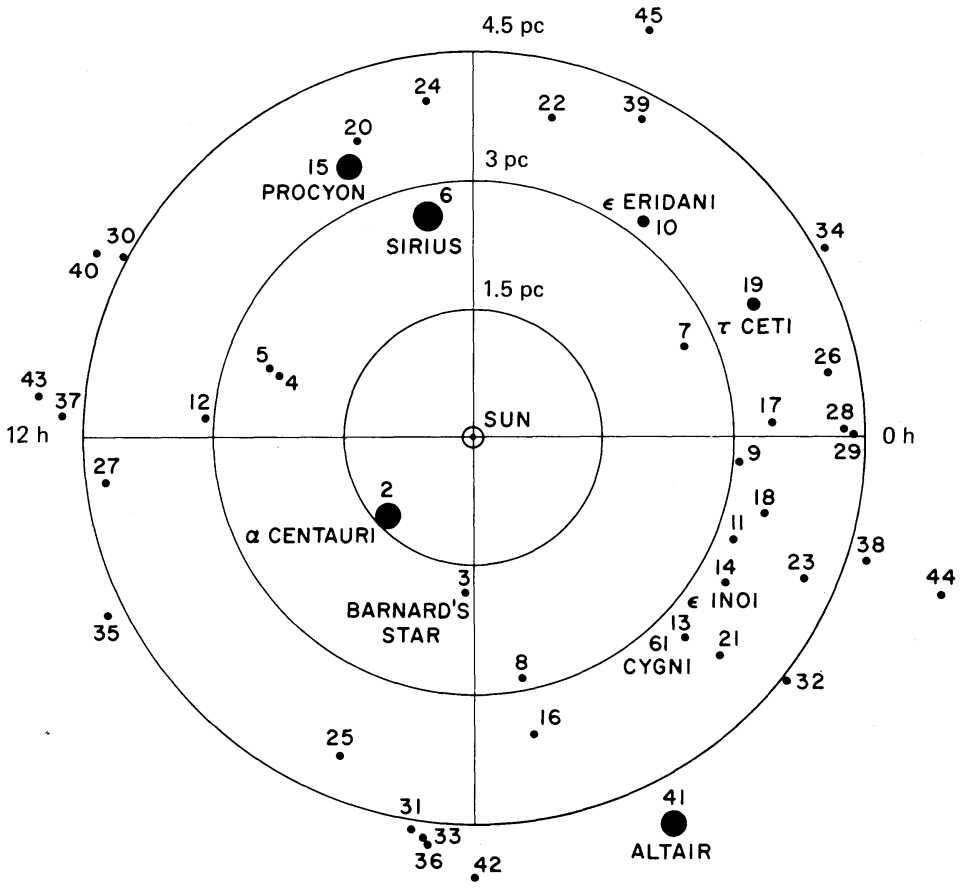
23	CD − 39°14192	21 14.3	− 39 04	0.260 ± 0.012	3.46	+21	M0 V	6.66	1.40	1.20	0.69	8.74	0.028
24	Kapteyn's star	5 09.7	− 45 00	0.256 ± 0.010	8.72	+245	sdM0 pec	8.84	1.56	1.05	0.77	10.88	0.0039
25	Krüger 60A	22 26.2	+ 57 27	0.253 ± 0.004	0.86	−26	dM3	9.85	1.62	1.25	1.14	11.87	0.0016
	Krüger 60B						dM5 e	11.3	1.8	1.3		13.3	0.0004
26	BD − 12°4523	16 27.5	− 12 32	0.247 ± 0.007	1.18	−13	dM5	10.11	1.60	1.16	1.20	12.07	0.0013
27	Ross 614 A	6 26.8	− 2 46	0.246 ± 0.004	1.00	+24	dM7 e	11.10	1.71	1.15	1.40	13.12	0.000 49
	Ross 614 B							14				16	0.000 04
28	Van Maanen's star	0 46.5	+ 5 09	0.232 ± 0.004	2.99	+54:	DG	12.37	0.56	0.02	0.16	14.20	0.000 18
29	Wolf 424 A	12 30.9	+ 9 18	0.230 ± 0.006	1.76	−5	dM6 e	13.16	1.80	1.18	1.62	14.97	0.000 09
	Wolf 424 B						dM6 e	13.4				15.2	0.000 07
30	CD − 37°15492	0 02.5	− 37 36	0.225 ± 0.012	6.11	+23	M4 V	8.56	1.46	1.03	0.92	10.32	0.0065
31	L 1159 − 16	1 57.5	+ 12 50	0.224 ± 0.004	2.09		dM8 e	12.26	1.82	1.35	1.35	14.01	0.000 22
32	BD + 50°1725	10 08.3	+ 49 42	0.222 ± 0.010	1.45	−26	K7 V	6.59	1.36	1.28	0.60	8.32	0.041
33	CD − 46°11540	17 24.9	− 46 51	0.216 ± 0.012	1.06		dM4	9.37	1.53	1.21	1.03	11.04	0.0033
34	G 158 − 27	0 04.2	− 7 48	0.214 ± 0.007	2.04		dM	13.74	1.95		1.52	15.39	0.000 06
35	CD − 49°13515	21 30.2	− 49 13	0.214 ± 0.010	0.81	+8	M1 V	8.67	1.46	1.05	0.93	10.32	0.0065
36	CD − 44°11909	17 33.5	− 44 17	0.213 ± 0.007	1.16		M5	10.96	1.65	1.20	1.26	12.60	0.000 79
37	BD + 68°946	17 36.7	+ 68 23	0.213 ± 0.006	1.31	−22	M3.5 V	9.15	1.50	1.08	1.10	10.79	0.0042
38	G 208 − 44 = A	19 52.3	+ 44 18	0.211 ± 0.004	0.74			13.41	1.90			15.03	0.000 08
	G 208 − 45 = B							13.99	1.98			15.61	0.000 05
39	BD − 15°6290	22 50.6	− 14 31	0.209 ± 0.007	1.14	+9	dM5	10.17	1.60	1.15	1.22	11.77	0.0017
40	*o* (40) Eri A	4 13.0	− 7 44	0.207 ± 0.003	4.08	−42	K1 V	4.43	0.82	0.44	0.31	6.01	0.34
	40 Eri B	4 13.1	− 7 44		4.07	−21	DA	9.52	0.03	−0.68	−0.10	11.10	0.0032
	40 Eri C					−45	dM4 e	11.17	1.66	0.83	1.31	12.75	0.000 69
41	BD + 20°2465	10 16.9	+ 20 07	0.206 + 0.006	0.49	+11	M4.5 V e	9.43	1.54	1.06	1.12	11.00	0.0035
42	L 145 − 141	11 43.0	− 64 33	0.206 ± 0.012	2.68		DC	11.50	0.19	−0.60	0.04	13.07	0.000 52
43	70 Oph A	18 02.9	+ 2 31	0.203 ± 0.006	1.12	−7	K0 V	4.22	0.86	0.51	0.30	5.76	0.43
	70 Oph B						K5 V	6.00				7.54	0.084
44	BD + 43°4305	22 44.7	+ 44 05	0.200 ± 0.004	0.83	−2	dM5 e	10.2	1.6	1.1	1.15	11.7	0.0018
45	Altair	19 48.3	+ 8 44	0.198 ± 0.006	0.66	−26	A7 IV–V	0.76	0.22	0.08	0.02	2.24	11.1
46	AC + 79°3888	11 44.6	+ 78 58	0.193 ± 0.007	0.89	−119	sdM4	10.8	1.60		1.18	12.23	0.0011
47	G 9 − 38 = A	8 55.4	+ 19 57	0.192 ± 0.004	0.89		m	14.06	1.84			15.48	0.000 06
	LP 426 − 40 = B						m	14.92	1.93			16.34	0.000 025
48	BD + 15°2620	13 43.2	+ 15 10	0.192 ± 0.007	2.30	+15	M4 V	8.49	1.44	1.10	0.86	9.91	0.0095

: denotes approximate value.

(Adapted from Landolt–Börnstein, V1/2C, Springer-Verlag, 1982.)

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Known stars within 5 parsecs of the Sun (in a sphere, projected on a plane). The numbers correspond to the order of radial distance from the Sun. The angular position on the plot is the star's right ascension. Stars that appear close together on the plot are not necessarily close in space, since the third dimension – for example, the star's declination – cannot be indicated. (Adapted from Roach, F. E. & Gordon, J. L., *The Light of the Night Sky*, D. Reidel Publishing Co., 1973.)



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Stars of large proper motion ($V < 8.05$)

Name	Constellation	V mag.	Annual motion	α 2000	δ 2000
Groombridge 1830	Ursa Major	6.45	7".05	$11^h 52^m 58^s.7$	+37° 43′ 07″
Lacaille 9352	Piscis Aus.	7.34	6.90	23 05 52.0	−35 51 12
61 Cygni	Cygnus	4.84	5.22	21 06 53.9	+38 44 58
Lalande 21185	Ursa Major	7.49	4.77	11 03 20.2	+35 58 13
ε Indi	Indus	4.69	4.70	22 03 21.5	−56 47 10
o^2 Eridani	Eridanus	4.43	4.08	04 15 16.2	−07 39 10
μ Cassiopeiae	Cassiopeia	5.17	3.75	01 08 16.2	+54 55 15
α^2 Centauri	Centaurus	1.39	3.68	14 39 35.4	−60 50 13
α^1 Centauri	Centaurus	0.00	3.68	14 39 36.7	−60 50 02
Lacaille 8760	Microscopium	6.68	3.46	21 17 15.1	−38 52 05
82 G Eridani	Eridanus	4.27	3.14	03 19 55.7	−43 04 10
268 G Ceti	Cetus	5.82	2.32	02 36 04.8	+06 53 13
Arcturus	Boötes	−0.04	2.28	14 15 39.6	+19 10 57

(List from *Sky Catalogue 2000.0*, Hirshfeld, A. & Sinnott, R., eds., Sky Publishing Corp., 1982.)

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The 21 fastest pulsars (as of August 1986)

Pulsar PSR	α 1950	δ 1950	P (s)	$\dot{P}$ (10^{-9} s d^{-1})	JD − 2440000	DM (pc cm^{-3})
1937+214[c]	$19^h37^m28^s.72$	21°28′ 1″.3	0.001 557 806 449 023	1.07×10^{-5}	5303	71.20
1855+09[c]	18 55 13.68	09 39 13.3	0.005 362 100 452 39	1.8×10^{-6}	6433	13.2943
1953+29[c]	19 53 26.7	29 00 42.0	0.006 133 17	$\leqslant 0.050$	5427	104.5
0531+21[a]	5 31 31.43	21 58 0.7	0.033 200 385 8	36.46	1994	56.791
1913+16[c]	19 13 12.48	16 01 8.4	0.059 029 995 272	0.000 76	2322	167.000
0833−45[b]	8 33 39.35	−45 00 8.6	0.089 234 713 88	10.8026	2701	69.080
1356−60	13 56 26.18	−60 23 36.2	0.127 500 776 85	0.547 65	3556	295.000
1930+22	19 30 12.49	22 15 19.0	0.144 427 889 857 53	4.992 17	2676	219.00
0355+54	3 55 0.45	54 04 42.6	0.156 380 055 92	0.379	1536	57.030
1804−08	18 04 53.91	−8 48 10.5	0.163 727 360 007	0.002 48	3557	112.800
0740−28	7 40 47.87	−28 15 32.6	0.166 753 902 088	1.454 79	3556	73.770
1541−52	15 41 12.59	−52 59 22.9	0.178 553 799 688	0.005 24	3556	35.200
1449−64	14 49 25.30	−64 01 0.5	0.179 483 983 915	0.237 42	3556	70.500
1821−19	18 21 2.78	−19 47 29.0	0.189 332 134 77	0.452 55	3557	225.700
1557−50	15 57 8.83	−50 35 55.7	0.192 598 318 85	0.4375	2554	270.00
1556−57	15 56 14.66	−57 42 47.4	0.194 453 886 93	0.183 58	3557	176.900
1915+13	19 15 21.57	13 48 28.7	0.194 626 341 491	0.622 33	2302	94.00

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0656+64[c]	6 56 30.00	64 20 0.0	0.1955	—	3513	5
1055−52	10 55 48.59	−52 10 51.9	0.197 107 608 187	0.504 01	3556	30.100
0743−53	7 43 50.50	−53 44 1.0	0.214 836 351 4	0.235 87	3780	122.300
1221−63	12 21 34.71	−63 51 16.3	0.216 474 842 97	0.428 09	3556	96.900

α, δ = position,
P = pulse period,
$\dot{P}$ = the rate of change of the period,
JD = Julian date of observation,

$$DM = \text{dispersion measure} = \int_0^d N_e \, dl,$$

where d = distance of the pulsar from the Sun,
N_e = electron number density in interstellar space.

The pulse arrival time for two different observing frequencies f_1 and f_2 differs by:

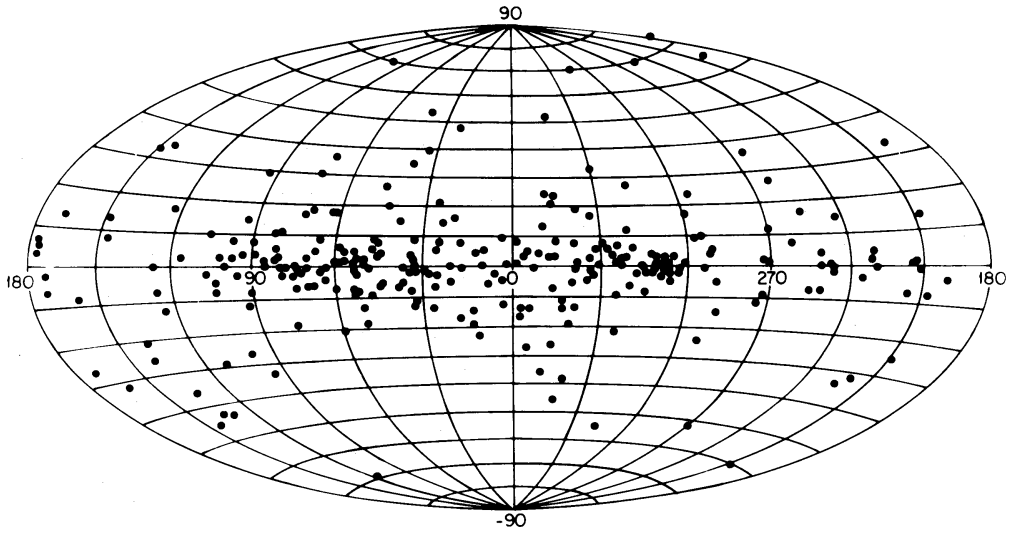
$$t_2 - t_1 = \frac{e^2}{2\pi m_e c}\left(\frac{1}{f_2^2} - \frac{1}{f_1^2}\right) DM.$$

[a] Crab pulsar.
[b] Vela pulsar.
[c] Binary pulsar.

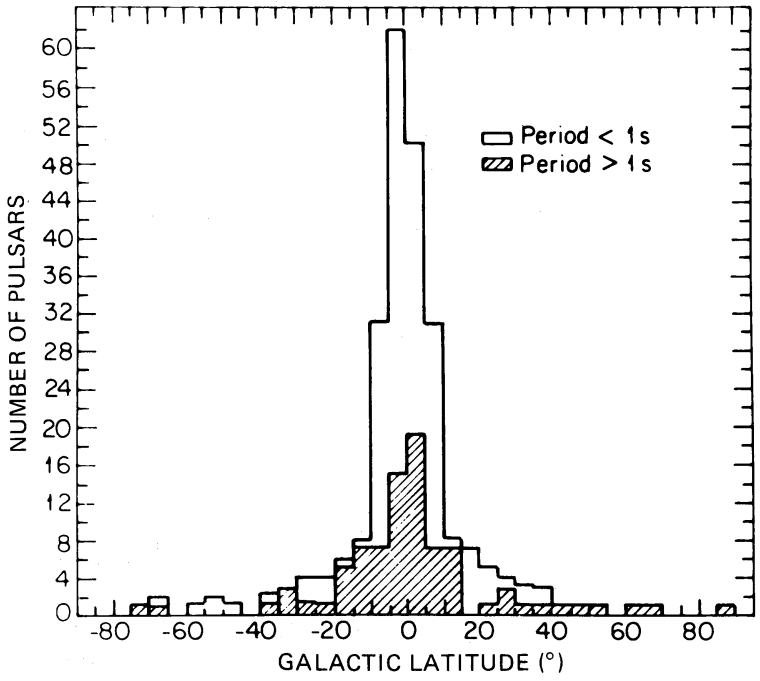
(Data from *Landolt-Börnstein*, Band 2c, Springer-Verlag, 1982, except PSR 1937+214: Baker, D. C. & Kulkarni, S. R., *Nature*, **301**, 314, 1983, PSR 1953+29: Boriakoff, V. *et al.*, *Nature*, **304**, 417, 1983 and PSR 1855+09: Segelstein, D. J. *et al.*, *Nature*, **322**, 714, 1986.)

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Galactic distribution of pulsars. In the adopted coordinates, 0° latitude corresponds to the Galactic plane, while 0° longitude, 0° latitude corresponds to the direction of the Galactic center. (Courtesy of Y. Terzian, Cornell University.)



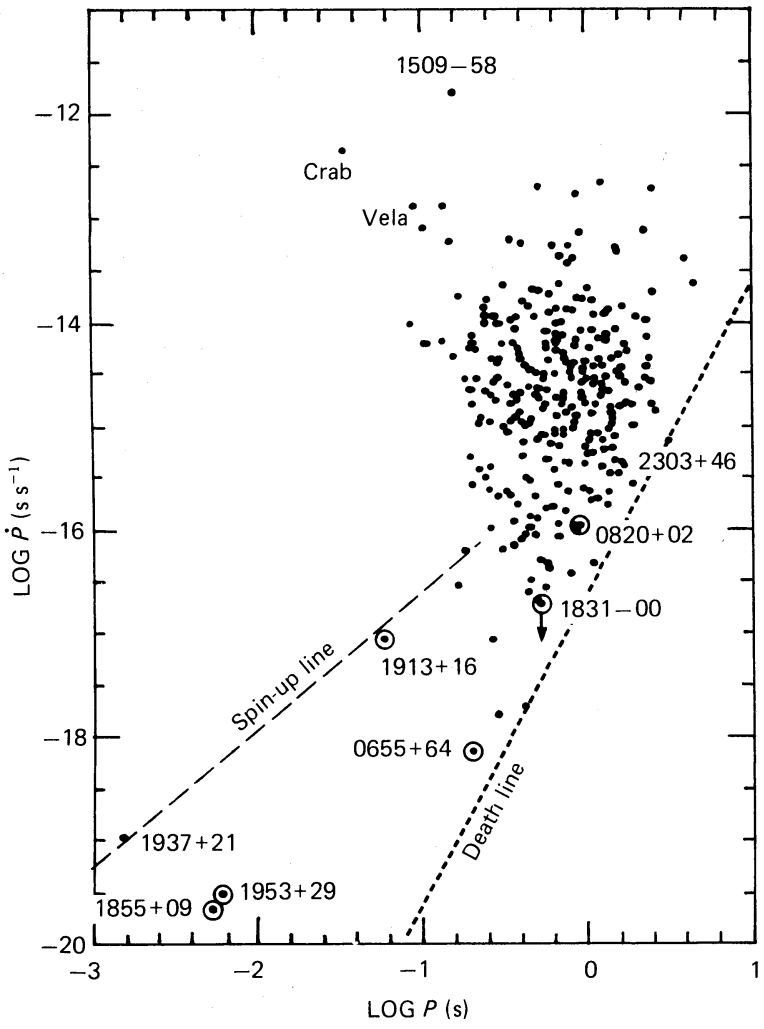
Distribution of pulsars in Galactic latitude. Latitude 0° corresponds to the Galactic plane. (Courtesy of Y. Terzian, Cornell University.)



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Pulsars *(cont.)*

Distribution of periods and period derivatives for 353 pulsars. The seven known binary pulsars, indicated by circles around the dots, have unusually small period derivatives and hence relatively weak magnetic fields. (Dewey, R. J. *et al.*, *Nature*, **322**, 712, 1986, with permission.)



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Parameters of binary radio pulsars

PSR	P (ms)	$\log \dot{P}$	$\log B^{(a)}$ (Gauss)	$\lvert z\rvert^{(b)}$ (pc)	$a_1 \sin i^{(c)}$ ($R_\odot$)	P_b (d)	e	$f(m_1, m_2)^{(d)}$ ($M_\odot$)	Likely $m_2^{(e)}$ ($M_\odot$)
1855+09	5.4	−19.7	8.5	20	4.0	12.33	0.000 02	0.0052	0.2–0.4
1953+29	6.1	−19.5	8.6	20	13.6	117.35	0.0003	0.0027	0.2–0.4
0655+64	195.6	−18.2	10.0	120	1.8	1.03	<0.000 05	0.0712	0.7–1.3
1913+16	59.0	−17.1	10.3	190	1.0	0.32	0.6171	0.1322	1.4
1831−00	520.9	< −17.0	< 10.9	190	0.3	1.81	<0.005	0.000 12	0.06–0.13
0820+02	864.9	−16.0	11.5	280	70.0	1232.40	0.0119	0.0030	0.2–0.4
2303+46	1066.4	−15.4	11.8	480	14.1	12.34	0.6584	0.2463	1.2–2.5

(a) $B = 3.2 \times 10^{19}(P\dot{P})^{1/2}$.

(b) The distance above the galactic plane.

(c) $R_\odot$ represents the Sun's radius as a unit of measurement.

(d) $f(m_1, m_2) = \dfrac{(m_2 \sin i)^3}{(m_1 + m_2)^2} = \dfrac{4\pi^2}{G} \dfrac{(a_1 \sin i)^3}{P_b^2}$, where m_1 and m_2 are the masses of the pulsar and companion, respectively, a_1 is the orbital semi-major axis; i is the angle between the plane of the orbit and the plane of the sky.

(e) $M_\odot$ represents the Sun's mass as a unit of measurement.

(List taken from Dewey, R. J. *et al.*, *Nature*, **322**, 712, 1986.)

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Name	α 2000	δ 2000	Diameter (′)	Distance (pc)	O stars	B stars	*RV* (km s^{-1})	Clusters	Stars
Cas OB4	$0^h28^m.4$	+62° 42′		2880	5	12	−43	103	
Cas OB14	0 28.8	+63 22		1110	0	3	−8		κ Cas
Cas OB1	1 00.8	+61 30	120	2510	0	5	−38	381?	
Cas OB8	1 46.2	+61 19		2880	1	10	−30	581, 663; 654?	
Per OB1	2 14.5	+57 19	360	2290	9	56	−41	h, χ Per	
Cas OB6	2 43.2	+61 23	480	2190	17	8	−47	IC 1805	
Cam OB1	3 31.6	+58 38		1000	3	9	−6	1444? 1502?	
Per OB3	3 27.8	+49 54		170					α, δ Per
Per OB2	3 42.2	+33 26	480 × 300	400	1	3			ζ, *o*, χ Per
Aur OB2	5 28.3	+34 54		3160	5	3	−13	1893, IC 410	
Aur OB1	5 21.7	+33 52	360 × 300	1320	5	5	−3	1912, 60; 1931?	
Gem OB1	6 09.8	+21 35	300	1510	4	13	+13	2175?	χ^2 Ori
Ori OB1	5 31.4	−2 41	960	460	9	6		Trapezium	θ, β, γ, δ, ε Ori
Mon OB1	6 33.1	+8 50	840 × 300	550	1	0	+22	2264	S Mon
Mon OB2	6 37.2	+4 50	360 × 250	1510	10	7	+28	2244	Plaskett's star
CMa OB1	7 07.0	−10 28	240	1320	4	3	+27	2335, 53; 2343?	
Pup OB1	7 54.8	−27 05	240 × 180	2510	7	0	+43	2467?	
Vel OB2	8 11.8	−47 50		460					Vela pulsar?
Vel OB1	8 49.9	−45 00	360 × 240	1400	5	11		2659?	
Car OB1	10 46.7	−59 05	120 × 66	2510	6	15		3293; IC 2581?	
Car OB2	11 06.0	−59 51	330 × 150	2000	8	6		3572, Tr 18	
Car OB4	11 08.3	−60 31	114 × 54					3590	
Cen OB2	11 35.3	−62 36	84 × 48	2500				IC 2944	λ Cen
Cen OB1	13 04.8	−62 04	360	2510	2	19		4755	χ Cru
Nor OB1	15 58.7	−54 30		2500	0	6		6031?	

Prominent OB associations *(cont.)*

Name	α 2000	δ 2000	Diameter (′)	Distance (pc)	O stars	B stars	*RV* (km s^{-1})	Clusters	Stars
Sco-Cen	16:^{h} ^{m}	−25:°		160				IC 2602?	α CMa, α Car, α Eri
Ara OB1	16 39.5	−46 46	270 × 180	1380				6169, 93	μ Nor
Sco OB1	16 53.5	−41 57	96 × 66	1910	18	10	−18	6231	ζ^1 Sco
Sco OB2	16 14.9	−25 55		160	0	3			α, β^1, δ Sco
Sgr OB1	18 07.9	−21 28	570 × 240	1580	8	9	−4	6514, 30–1	μ Sgr
Sgr OB4	18 14.4	−19 03		2400	1	6	+3	6603	
Ser OB1	18 20.8	−14 35	300 × 180	2190	9	9	−23	6611	
Ser OB2	18 18.6	−11 58	500:	2000:	9	6	+6	6604?	
Vul OB1	19 44.0	+24 13		2000	5	7	+8	6823	
Cyg OB3	20 04.7	+35 50		2290	9	15	0	6871?	Cyg X−1
Cyg OB1	20 17.8	+37 38	420 × 240	1820	12	28	−7	6913, IC 4996	
Cyg OB9	20 23.3	+39 56		1200	7	7	−20	6910	
Cyg OB2	20 32.4	+41 17	30	1820	13	2			
Cyg OB4	21 13.1	+37 52		1000					σ Cyg
Cyg OB7	21 02.7	+49 43		830	3	6	−10		α Cyg
Cep OB2	21 47.9	+61 04	460	830	8	9	−20	7160, IC 1396	μ, ν, λ Cep
Cep OB1	22 24.6	+55 14	210	3470	7	26	−51	7380?	β Cep
Lac OB1	22 41.2	+39 05	900 × 540	600	1	0			10 Lac
Cep OB3	23 00.4	+64 03		870	3	3	−21		
Cas OB5	23 58.7	+60 22	150	2510	5	10	−46	7788; 7790?	ρ Cas
Cep OB4	23 59.5	+67 35		840	2	0			

: denotes approximate value.
(Adapted from *Sky Catalogue 2000.0*, Vol. 2, Sky Publishing Corp., 1985.)

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The orbital elements of some binary stars

Name	α 2000	δ 2000	Period, P (mean solar years)	Epoch of periastron, t	Longitude of periastron, ω (°)	Eccentricity, e	Semi-major axis of orbit, a (arcsec)	Inclin. orbit, i (°)	Position angle of ascending node, Ω (°)	Distance, d (pc)
η CrB	$15^h23^m21^s$	30° 17′	41.623	1934.008	219.907	0.2763	0.907	59.025	23.717	14
γ Vir	12 41 40	−01 27	171.37	1836.433	252.88	0.8808	3.746	146.05	31.78	11
η Cas	00 49 06	57 49	480	1889.6	268.59	0.497	11.9939	34.76	278.42	5.9
ζ Ori	05 40 46	−01 56	1508.6	2070.6	47.3	0.07	2.728	72.0	155.5	340
α CMa (Sirius)	06 45 09	−16 43	50.09	1894.13	147.27	0.5923	7.500	136.53	44.57	2.7
δ Gem	07 20 07	21 59	1200	1437	57.19	0.1100	6.9753	63.28	18.38	18
α Gem (Castor)	07 34 36	31 53	420.07	1965.3	261.43	0.33	6.295	115.94	40.47	14
α CMi (Procyon)	07 39 18	5 14	40.65	1927.6	269.8	0.40	4.548	35.7	284.3	3.5
α Cen	14 39 36	−60 50	79.920	1955.56	231.560	0.516	17.583	79.240	204.868	1.3
α Sco (Antares)	16 29 24	−26 26	900	1889.0	0.0	0.0	3.21	86.3	273.0	100

a semi-major axis,
P period of revolution,
M_1, M_2 stellar masses,

$$\frac{a^3}{P^2} = \frac{G}{4\pi^2}(M_1 + M_2),$$ where G is the gravitational constant (Kepler's third law).

If we express masses in solar masses, periods in years, and distances in astronomical units, we have

$$(M_1 + M_2)P^2 = a^3 \quad (a\ (\text{AU}) = a\ (\text{arcsec}) \times d\ (\text{pc})).$$

e eccentricity,
t epoch of the periastron passage (the closest approach of the stars),
Ω position of the ascending node. The nodes are points of intersection of the relative orbit and a plane tangential to the celestial sphere at the position of the bright component,
ω longitude of the periastron, the angle between the radius vector to the ascending node and that in the direction of the periastron, measured from the node to the periastron in the direction of the orbital motion,
i inclination, the angle between the orbital plane and the plane tangential to the celestial sphere.
(Adapted from Duffett-Smith, P., *Practical Astronomy With Your Calculator*, Cambridge University Press.)

Main class		Subclass	Brightness variation (mag)	Period (d)	Typical representative	Brightness[a] (mag) max	Brightness[a] (mag) min	Period (d)
Cepheids	C	Classical cepheids	0.1–2.0	1–50 or 70	TW CMa	9.5	11.0 p	6.99
	Cδ	Classical cepheids	0.1–2.0	1–50 or 70	δ Cep	4.1	5.2 p	5.37
	CW	Long-period cepheids	0.1–2.0	1–50 or 70	W Vir	9.9	11.3 p	17.29
	I	Irregular variables	—	—	RX Cep	7.5	7.8 v	—
	Ia	Irregular variables	—	—	V395 Cyg	7.8	8.4 v	—
	Ib	Irregular variables	—	—	CO Cyg	9.6	10.6 v	—
	Ic	Irregular variables	—	—	TZ Cas	9.2	10.5 v	—
Long-period variables	M	Mira Ceti stars	2.5–5.0 and more	80–1000	*o* Cet	2.0	10.1 v	331.62
Red giant variables	SR	Semiregular variables	1–2.0	30–1000	VW UMa	8.4	9.1 p	125
	SRa	Semiregular variables	< 2.5	—	Z Aqr	9.5	12.0 p	136.9
	SRb	Semiregular variables	—	—	AF Cyg	7.4	9.4 p	94.1
	SRc	Semiregular variables	—	—	μ Cep	3.6	5.1 v	—
	SRd	Semiregular variables	—	—	UU Her	8.5	10.6 p	—
RR Lyrae variables	RR	Cluster variables	< 1–2.0	0.05–1.2	V756 Oph	12.3	13.7 p	—
	RRa	Cluster variables	< 1.5	0.5 and 0.7	RR Lyr	6.94	8.03 p	0.567
	RRc	Cluster variables	—	0.3	SX UMa	10.6	11.2 p	0.307
RV Tauri variables	RV	Variable supergiants	3	30–150	EP Lyr	10.2	11.6 p	83.43
	RVa	Red-giant variables	3	30–150	AC Her	7.4	9.2 p	75.46
	RVb	Red-giant variables	3	30–150	R Sge	9.0	11.2 p	70.594
	βC	β Cephei V. β Canis Major V.	0.1	0.1–0.3	β Cep	3.3	3.35 p	0.190
	δSc	Scuti variables	< 0.25	1.0	δ Sct	4.9	5.19 p	0.194
	α^2CV	α^2 Canis Ven. variables	< 0.1	1–25	α^2 CVn	3.0	3.1 p	5.47

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Eruptive variables	N	Novae	7–16	—	—	—	—	—
	Na	Novae	7–16	—	V603 Aql	−1.1	10.8 p	—
	Nb	Novae	7–16	—	RR Pic	1.2	12.8 p	—
	Nc	Novae	7–16	—	RT Ser	10.6	16 p	—
	Nd	Recurrent novae	7–16	—	T GrB	2.0	10.8 v	29 000
	Ne	Nova-like variables	—	—	P Cyg	3.0	6 v	—
	SN	Supernovae	20	—	CM Tau (SN 1054 Crab Nebula)	−6	15.9 p	—
	RCB	R Coronae Borealis variables	1–9	10–100	R CrB	5.8	14.8 v	—
	RW	RW Aurigae variables	—	—	RW Aur	9.6	13.6 p	—
	UG	U Geminorum variables (SS Cygni variables)	2–6	20–600	U Gem	8.9	14.0 v	103
	UV	UV Ceti variables	1–6	—	UV Cet	7.0	12.9 v	—
	Z	Z Camelopardalis variables	2–5	10–40	—	—	—	—
Eclipsing variables	E	Eclipsing variables	—	—	QX Cas	10.2	10.6 p	—
	EA	Algol variables	—	0.2–10 000	β Per	2.2	3.47 v	2.867
	EB	β Lyrae variables	< 2.0	> 1	β Lyr	3.4	4.34	12.908
	EW	W Ursae Majoris variables	0.8	1	W UMa	8.3	9.03 p	0.334
	Ell	Ellipsoid variables	—	—	b Per	4.6	4.66 p	1.527
Unclassifiable variables		—	—	—	V389 Cyg	5.5	5.69 p	—

[a] p = photographic, v = visual.

(Adapted from Roth, G. D., ed., *Handbuch für Sternfreunde*, Springer-Verlag, 1967.)

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Galactic supernova remnants

Name	Galactic coordinates l^{II}, b^{II}	α 1950	δ 1950	Radio size	Optical size
CTA 1	119.°53, +9.°77	$00^h04^m18^s$	+72°04′.5	90′	50′ × 90′
Tycho	120.09, +1.41	00 22 33	+63 51.8	8′	8′
HB 3	132.70, +1.30	02 14	+62 18	140′	...
HB 9	160.39, +2.75	04 57	+46 36	130′ × 155′	90′ × 125′
OA 184	166.07, +4.40	05 15 38	+41 46	70′ × 90′	70′ × 80′
VRO 42.05.01	166.27, +2.53	05 23 21	+43 00	70′ × 75′	35′ × 40′
S 147	180.33, −1.68	05 36 45	+27 44.5	175′	195′ × 200′
Crab	184.55, −5.78	05 31 31	+21 58.9	290″ × 420″	290″ × 420″
IC 443	189.01, +3.02	06 14 06	+22 37.2	47′ × 54′	48′
Monoceros	205.62, −0.10	06 35	+06 30	210′	180′ × 200′
Puppis	260.40, −3.42	08 20 30	−42 50	45′ × 65′	50′ × 80′
Vela	263.37, −3.01	08 32	−45 00	300′	270′
MSH 10−53	284.17, −1.78	10 15 40	−58 40.5	33′ × 50′	1′ × 5′
RCW 86	315.44, −2.33	14 39 08	−62 15	55′	8′ × 31′
RCW 89	320.36, −0.97	15 09 30	−58 46	8′:	450″ × 580″
RCW 103	332.43, −0.39	16 13 54	−50 55.8	7′	5′.7 × 9′.5
Kes 45	342.05, +0.13	16 50 11	−43 30.3	30′	... × 20′
Kepler	004.52, +6.82	17 27 41	−21 26.6	3′	21″ × 64″
W28	006.46, −0.09	17 57 36	−23 25	30′	30′
3C 400.2	053.62, −2.23	19 36 30	+17 08	20′	4′ × 6′
DR 4	078.13, +1.81	20 20 38	+40 03.4	⩽3′	2′ × 3′
Cygnus	074.27, −8.49	20 49 30	+30 45	160′ × 240′	160′ × 210′
Cas A	111.73, −2.13	23 21 10	+58 32.4	130′	130′
CTB 1	116.94, +0.18	23 56 45	+62 10	35′: × 45′:	32′

: denotes approximate value.

(Adapted from van den Bergh *et al.*, *Ap. J. Suppl.*, **26**, 19, 1973.)

Henry Draper (HD) spectral classification

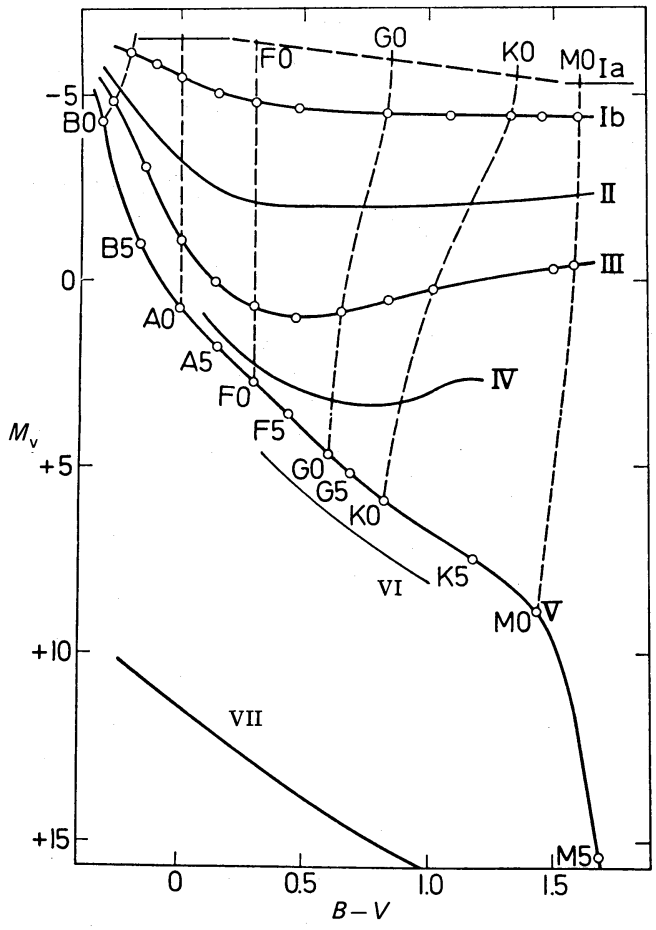
Class	Class characteristics
O	Hot stars with He II absorption
B	He I absorption; H developing later
A	Very strong H, decreasing later; Ca II increasing
F	Ca II stronger; H weaker; metals developing
G	Ca II strong; Fe and other metals strong; H weaker
K	Strong metallic lines; CH and CN bands developing
M	Very red; TiO bands developing strongly

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Spectral type and luminosity class (MK, or Yerke's classification)

Luminosity class		Examples:	Spectral type
Ia	Supergiants	α Boo (Arcturus)	K2 III
Ib	Supergiants	α CMi (Procyon)	F5 IV
II	Bright giants	β Gem (Pollux)	K0 III
III	Giants	α Lyr (Vega)	A0 V
IV	Subgiants	α UMi (Polaris)	F8 Ib
V	Main sequence (dwarfs)	α CMa (Sirius)	A1 V
VI	Subdwarfs	α Cyg (Deneb)	A2 Ia
VII	White dwarfs	α Leo (Regulus)	B7 V
		β Ori (Rigel)	B8 Ia
		Sun	G2 V

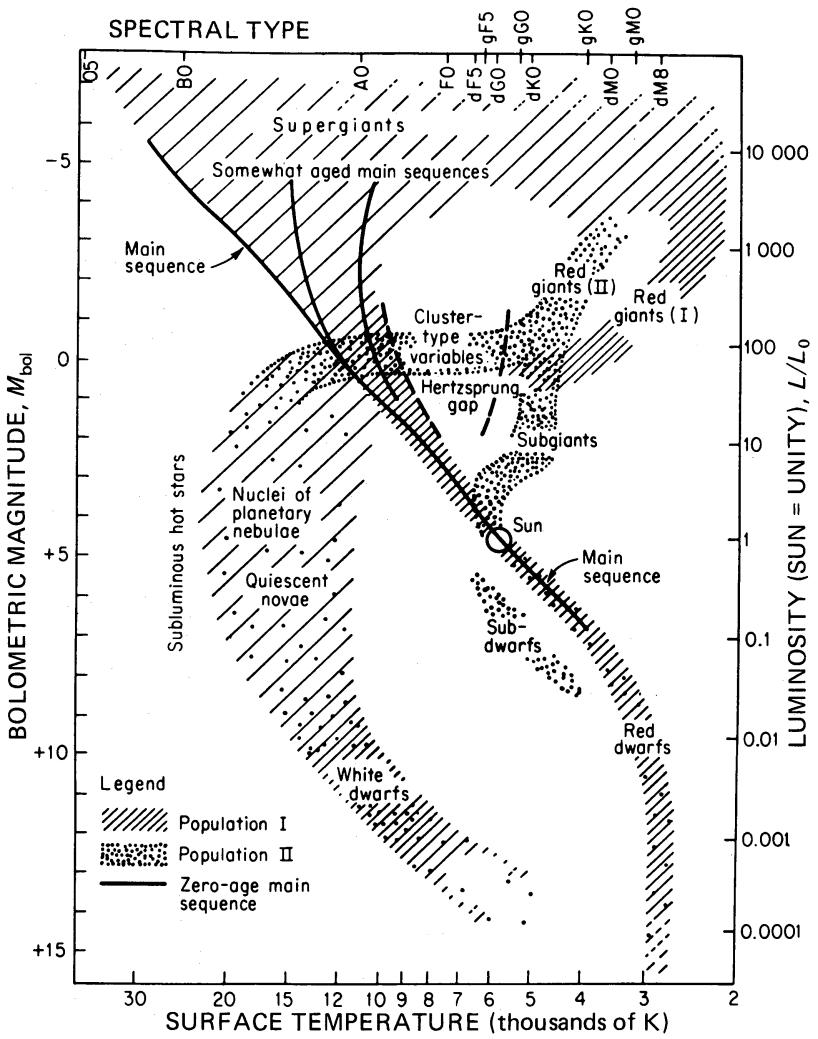
Spectral type and luminosity class of the MK classification; dependence on color index B − V and visual absolute magnitude M_v. (Adapted from Unsoeld, A., *The New Cosmos*, Springer-Verlag, 1969.)



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Hertzsprung–Russell diagram

Hertzsprung–Russell or temperature luminosity diagram. (Adapted from Goldberg, L. & Dyer, E. R. in *Science in Space*, L. V. Berkner & H. Odishaw, eds., McGraw-Hill Book Company, 1961.)



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An incomplete list of astrophysically important infrared and visible spectral features

Identification	Wavelength (Å)†	Identification	Wavelength (Å)
He I	10 830	O II	4649
C I	10 691	N III	4641
Si I	10 689	N III	4634
Si I	10 627	Mg I	4571
Si I	10 603	He II	4541
Si I	10 371	Mg II	4481
He II	10 124	He I	4472
He II	10 120	He I	4471
Na I	9961	He I	4388
C III	9710	Fe I	4384
O I	8446	[O III]	4363
He II	8237	H I γ	4340
O I	7774	O II	4318
He I	7065	G band[b]	4300
H I α	6563	Ca I	4227
[O I]	6363[a]	He II	4200
[O I]	6300	H I δ	4102
Na I (D)	5896	He II	4100
Na I (D)	5890	N III	4097
He I	5876	Si IV	4089
He II	5412	O II	4073
Fe XIV	5303	He I	4026
Mg I	5175[b]	H I ε	3970
Mg I	5173	Ca II (H)	3968
[O III]	5007	[Ne III]	3968
[O III]	4959	He I	3965
He I	4922	Ca II (K)	3934
H I β	4861	[Ne III]	3869
He II	4686	He I	3820
C IV	4658	O III	3760
O II	4650	[O II]	3727
C III	4650	[Ne V]	3426

† $h\nu$ (eV) = 123 98.54/λ (Å).
[a] Forbidden transitions are noted by brackets.
[b] Superposition of CH band and metallic lines.

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The main sequence[a]

Sp (V)	$U-V$	$B-V$	$V-R$	$V-I$	$V-J$	$V-K$	$V-L$	$V-M$	$V-N$	BC	T_e (K)
O5–7	−1.46	−0.32	−0.15	−0.47	−0.73	−0.94	−1.01	—	—	—	38 000
O8–9	−1.44	−0.31	−0.15	−0.47	−0.73	−0.94	−1.01	—	—	—	35 000[b]
O9.5	−1.40	−0.30	−0.14	−0.46	−0.73	−0.94	−1.00	—	—	−3.34	31 900
B0	−1.38	−0.30	−0.13	−0.42	−0.70	−0.93	−0.99	—	—	−3.17	30 000
B0.5	−1.29	−0.28	−0.12	−0.39	−0.66	−0.88	−0.93	—	—	−2.80	27 000[b]
B1	−1.19	−0.26	−0.11	−0.36	−0.61	−0.81	−0.86	—	—	−2.50	24 200
B2	−1.10	−0.24	−0.10	−0.32	−0.55	−0.74	−0.77	—	—	−2.23	22 100
B3	−0.91	−0.20	−0.08	−0.27	−0.45	−0.61	−0.63	—	—	−1.77	18 800
B5	−0.72	−0.16	−0.06	−0.22	−0.35	−0.47	−0.48	—	—	−1.39	16 400
B6	−0.63	−0.14	−0.06	−0.19	−0.30	−0.41	−0.41	—	—	−1.21	15 400
B7	−0.54	−0.12	−0.04	−0.17	−0.25	−0.35	−0.34	—	—	−1.04	14 500
B8	−0.39	−0.09	−0.02	−0.12	−0.17	−0.24	−0.22	—	—	−0.85	13 400
B9	−0.25	−0.06	0.00	−0.06	−0.09	−0.14	−0.11	—	—	−0.66	12 400
A0	0.00	0.00	+0.02	0.00	−0.01	−0.03	0.00	−0.03	−0.03	−0.40	10 800
A2	+0.12	+0.06	+0.08	+0.09	+0.11	+0.13	+0.16	+0.13	+0.13	−0.25	9730
A5	+0.25	+0.14	+0.16	+0.22	+0.27	+0.36	+0.40	+0.36	+0.36	−0.15	8620
A7	+0.30	+0.19	+0.19	+0.28	+0.35	+0.46	+0.52	+0.46	+0.46	−0.12	8190
F0	+0.37	+0.31	+0.30	+0.47	+0.58	+0.79	+0.86	+0.79	+0.79	−0.08	7240
F2	+0.39	+0.36	+0.35	+0.55	+0.68	+0.93	+1.07	+0.93	+0.93	−0.06	6930
F5	+0.43	+0.43	+0.40	+0.64	+0.79	+1.07	+1.25	+1.07	+1.07	−0.04	6540

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F8	+0.60	+0.54	+0.47	+0.76	+0.96	+1.27	+1.45	+1.27	+1.27	−0.05	6200
G0	+0.70	+0.59	+0.50	+0.81	+1.03	+1.35	+1.53	+1.35	+1.35	−0.06	5920
G2	+0.79	+0.63	+0.53	+0.86	+1.10	+1.44	+1.61	+1.44	+1.44	−0.07	5780
G5	+0.86	+0.66	+0.54	+0.89	+1.14	+1.49	+1.67	—	—	−0.10	5610
G8	+1.06	+0.74	+0.58	+0.96	+1.24	+1.63	+1.85	—	—	−0.15	5490
K0	+1.29	+0.82	+0.64	+1.06	+1.38	+1.83	+2.00	—	—	−0.19	5240
K2	+1.60	+0.92	+0.74	+1.22	+1.57	+2.15	+2.24	—	—	−0.25	4780
K5	+2.18	+1.15	+0.99	+1.62	+2.04	+2.75	+2.84	—	—		
K7	+2.52	+1.30	+1.15	+1.93	+2.36	+3.21	+3.40	—	—	−0.65	4410
										−0.90	4160
M0	+2.67	+1.41	+1.28	+2.19	+2.71	+3.60	+3.78	—	—	−1.20	3920
M1	+2.70	+1.48	+1.40	+2.45	+3.06	+3.95	+4.15	—	—	−1.48	3680
M2	+2.69	+1.52	+1.50	+2.69	+3.37	+4.27	+4.47	—	—	−1.76	3500
M3	+2.70	+1.55	+1.60	+2.94	+3.66	+4.57	+4.79	—	—	−2.03	3360
M4	+2.70	+1.56	+1.70	+3.19	+3.97	+4.87	+5.20	—	—	−2.31	3230
M5	+2.80	+1.61	+1.80	+3.47	+4.28	+5.17	(+5.54)	—	—	−2.62	3120
M6	+2.99	+1.72	+1.93	+3.76	+4.63	+5.58	(+6.03)	—	—	—	—
M7	+3.24	+1.84	+2.20	+4.20	+5.20	+6.18	—	—	—	—	—
M8	(+3.50)	(+2.00)	(+2.50)	(+4.70)	(+5.80)	(+6.75)	—	—	—	−4.20	2660

Bolometric corrections, BC, effective temperatures, T_e, and colors for stars of various spectral types. $m_b = BC + V$, where m_b and V are the bolometric and visual magnitudes, respectively.

[a] Morgan & Keenan classification of spectral types.

[b] Interpolated values.

(Adapted from Johnson, H., *Ann. Rev. Astron. and Astrophys.*, **4**, 193, 1966 and for BC and T_e, Lang, K., *Astrophysical Formulae*, Springer-Verlag, 1974.)

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Giant stars

Sp (III)	$U-V$	$B-V$	$V-R$	$V-I$	$V-J$	$V-K$	$V-L$	$V-M$	$V-N$	BC	T_e (K)
G5	+1.55	+0.92	+0.69	+1.17	+1.52	+2.08	+2.18	+2.02	+2.05	−0.20	5010
G8	+1.64	+0.95	+0.70	+1.18	+1.56	+2.16	+2.27	+2.09	+2.12	−0.21	4870
K0	+1.93	+1.04	+0.77	+1.30	+1.71	+2.35	+2.47	+2.25	+2.28	−0.30	4720
K1	+2.13	+1.10	+0.81	+1.37	+1.80	+2.48	+2.61	+2.36	+2.39	−0.36	4580
K2	+2.32	+1.16	+0.84	+1.42	+1.87	+2.59	+2.73	+2.45	+2.48	−0.42	4460
K3	+2.74	+1.30	+0.96	+1.61	+2.12	+2.92	+3.07	+2.75	+2.80	−0.59	4210
K4	+3.07	+1.41	+1.06	+1.81	+2.36	+3.24	+3.39	+3.05	+3.11	−0.79	4010
K5	+3.34	+1.54	+1.20	+2.10	+2.71	+3.67	+3.83	+3.47	+3.54	−1.08	3780
M0	+3.43	+1.55	+1.23	+2.17	+2.82	+3.79	+3.96	+3.59	+3.65	−1.17	3660
M1	+3.48	+1.56	+1.28	+2.27	+2.90	+3.92	+4.09	+3.72	+3.78	−1.25	3600
M2	+3.51	+1.59	+1.34	+2.44	+3.08	+4.11	+4.29	+3.91	+3.97	−1.41	3500
M3	+3.51	+1.60	+1.48	+2.79	+3.51	+4.58	+4.77	+4.39	+4.45	−1.80	3300
M4	+3.32	+1.59	+1.74	+3.39	+4.26	+5.24	+5.44	+5.10	+5.14	−2.44	3100
M5	+3.00	+1.55	+2.18	+4.14	+5.04	+6.06	+6.31	+6.00	+6.00	−3.23	2950
M6	+2.43	+1.54	+2.80	+5.06	+5.86	+7.01	+7.39			−4.15	2800

Bolometric corrections, BC, effective temperatures, T_e, and colors for stars of various spectral types. $m_b = BC + V$, where m_b and V are the bolometric and visual magnitudes respectively.

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Classification and absolute magnitude of stars (M_v)

Sp	Supergiants Ia	Supergiants Ib	Bright giants II	Giants III	Sub-giants IV	Main sequence dwarfs V	ZAMS[a] V	White dwarfs VII	Population II: Sub-dwarfs VI	Population II: Red branch	Population II: Horiz. branch
O5	−6.4			−5.4		−5.7					
B0	−6.7	−6.1	−5.4	−5.0	−4.7	−4.1	−3.3	+10.2			
B5	−6.9	−5.7	−4.3	−2.4	−1.8	−1.1	−0.2	+10.7			+2.3
A0	−7.1	−5.3	−3.1	−0.2	+0.1	+0.7	+1.5	+11.3			+0.8
A5	−7.7	−4.9	−2.6	+0.5	+1.4	+2.0	+2.4	+12.2			+0.5
F0	−8.2	−4.7	−2.3	+1.2	+2.0	+2.6	+3.1	+12.9			+0.4
F5	−7.7	−4.7	−2.2	+1.4	+2.3	+3.4	+3.9	+13.6	+4.8	+4.8	+0.4
G0	−7.5	−4.7	−2.1	+1.1	+2.9	+4.4	+4.6	+14.3	+5.7	+4.1	+0.3
G5	−7.5	−4.7	−2.1	+0.7	+3.1	+5.1	+5.2	+14.9	+6.4	+2.0	−0.1
K0	−7.5	−4.6	−2.1	+0.5	+3.2	+5.9	+6.0	+15.3	+7.3	−0.2	−0.6
K5	−7.5	−4.6	−2.2	−0.2		+7.3	+7.3	+15	+8.4	−2.2	−2.2
M0	−7.5	−4.6	−2.3	−0.4		+9.0	+9.0	+15	+10	−3	−3
M2	−7		−2.4	−0.6		+10.0	+10.0		+12		
M5				−0.8		+11.8	+11.8		+14		
M8						+16			+16		

Relation between absolute magnitude M_v and emission line width W (FWHM in km s^{-1}):

Emission line	*Relation*
Ca II K	$M_v = 27.59 - 14.94 \log W$ (Wilson–Bappu)
Mg II K	$M_v = 34.93 - 15.15 \log W$
H Lα	$M_v = (40.2 \pm 4.5) - (14.7 \pm 1.6) \log W$

[a] Zero age main sequence.

(After Allen, C. W., *Astrophysical Quantities*, The Athlone Press, 1973.)

Stellar mass, luminosity, radius and density (luminosity and radius with mass; white dwarfs omitted)

$\log(M/M_\odot)$	$\log(L/L_\odot)$	M_{bol}	M_v	M_B	$\log(R/R_\odot)$ main seq.
−1.0	−2.9	+12.1	15.5	+17.1	−0.9
−0.8	−2.5	+10.9	13.9	+15.5	−0.7
−0.6	−2.0	+9.7	12.2	+13.9	−0.5
−0.4	−1.5	+8.4	10.2	+11.8	−0.3
−0.2	−0.8	+6.6	7.5	+8.7	−0.14
0.0	0.0	+4.7	4.8	+5.5	0.00
+0.2	+0.8	+2.7	2.7	+3.0	+0.10
+0.4	+1.6	+0.7	1.1	+1.1	+0.32
+0.6	+2.3	−1.1	−0.2	−0.1	+0.49
+0.8	+3.0	−2.9	−1.1	−1.2	+0.58
+1.0	+3.7	−4.6	−2.2	−2.4	+0.72
+1.2	+4.4	−6.3	−3.4	−3.6	+0.86
+1.4	+4.9	−7.6	−4.6	−4.9	+1.00
+1.6	+5.4	−8.9	−5.6	−6.0	+1.15
+1.8	+6.0	−10.2	−6.3	−6.9	+1.3

(After Allen, C. W., *Astrophysical Quantities*, Athlone Press, 1973.)

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Stellar mass, luminosity, radius and density (mass, radius, luminosity, and mean density with spectral class)[a]

	$\log(M/M_\odot)$			$\log(R/R_\odot)$			$\log \bar{\rho}$ (g cm^{-3})			$\log(L/L_\odot)$		
Sp	I	III	V	I	III	V	I	III	V	I	III	V
O5	+2.2		+1.6			+1.25			−2.0			+5.7
B0	+1.7		+1.25	+1.3	+1.2	+0.87	−2.1		−1.2	+5.4		+4.3
B5	+1.4		+0.81	+1.5	+1.0	+0.58	−2.9		−0.78	+4.8		+2.9
A0	+1.2		+0.51	+1.6	+0.8	+0.40	−3.5		−0.55	+4.3		+1.9
A5	+1.1		+0.32	+1.7		+0.24	−3.8		−0.26	+4.0		+1.3
F0	+1.1		+0.23	+1.8		+0.13	−4.2		−0.01	+3.9		+0.8
F5	+1.0		+0.11	+1.9	+0.6	+0.08	−4.5		+0.03	+3.8		+0.4
G0	+1.0	+0.4	+0.04	+2.0	+0.8	+0.02	−4.9	−1.8	+0.13	+3.8	+1.5	+0.1
G5	+1.1	+0.5	−0.03	+2.1	+1.0	−0.03	−5.2	−2.4	+0.20	+3.8	+1.7	−0.1
K0	+1.1	+0.6	−0.11	+2.3	+1.2	−0.07	−5.7	−2.9	+0.25	+3.9	+1.9	−0.4
K5	+1.2	+0.7	−0.16	+2.6	+1.4	−0.13	−6.4	−3.4	+0.38	+4.2	+2.3	−0.8
M0	+1.2	+0.8	−0.33	+2.7		−0.20	−6.7	−4	+0.4	+4.5	+2.6	−1.2
M2	+1.3		−0.41	+2.9		−0.3	−7.2		+0.7	+4.7	+2.8	−1.5
M5			−0.67			−0.5			+1.0		+3.0	−2.1
M8			−1.0			−0.9			+1.8			−3.1

[a] I = supergiant, III = giant, V = dwarf.
A single column between III and V represents main sequence.
(After Allen, C. W.. *Astrophysical Quantities*, Athlone Press, 1973.)

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Present-day mass function (PDMF)

M_v	$\phi(M_v)$ (stars pc^{-3} mag^{-1})	$\log M/M_\odot$	$-\frac{dM_v}{d\log M}$	$2H$ (pc)	$\log T_{MS}$ (y)	f_{MS}	$\phi_{MS}(\log M)$ (stars pc^{-2} log M^{-1})
−6	1.49(−8)*	2.07	3.7	180	6.42	0.40	3.97(−6)*
−5	7.67(−8)	1.80	3.7	180	6.50	0.40	2.04(−5)
−4	3.82(−7)	1.53	3.7	180	6.58	0.41	1.04(−4)
−3	1.80(−6)	1.26	3.7	180	6.84	0.42	5.03(−4)
−2	7.86(−6)	0.99	3.7	180	7.19	0.43	2.25(−3)
−1	3.07(−5)	0.72	3.7	180	7.68	0.46	9.41(−3)
0	1.04(−4)	0.45	10.8	180	8.36	0.50	1.01(−1)
1	2.95(−4)	0.36	10.8	180	8.62	0.56	3.21(−1)
2	6.94(−4)	0.26	10.8	180	8.93	0.64	8.63(−1)
3	1.36(−3)	0.17	10.8	300	9.24	0.78	3.44(+0)
4	2.26(−3)	0.08	10.8	465	9.60	0.98	1.11(+1)
5	3.31(−3)	−0.02	10.8	630	9.83	1.00	2.25(+1)
6	4.41(−3)	−0.11	10.8	650	10.28	1.00	3.10(+1)
7	5.48(−3)	−0.20	10.8	650	—	1.00	3.85(+1)
8	6.52(−3)	−0.29	10.8	650	—	1.00	4.58(+1)
9	7.53(−3)	−0.39	10.8	650	—	1.00	5.29(+1)
10	8.52(−3)	−0.48	10.8	650	—	1.00	5.98(+1)

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11	9.54(−3)	−0.57	10.8	650	—	1.00	6.70(+1)
12	1.06(−2)	−0.67	10.8	650	—	1.00	7.44(+1)
13	1.17(−2)	−0.76	10.8	650	—	1.00	8.21(+1)
14	1.29(−2)	−0.85	10.8	650	—	1.00	9.06(+1)
15	1.41(−2)	−0.94	10.8	650	—	1.00	9.90(+1)
16	1.41(−2)	−1.04	10.8	650	—	1.00	9.90(+1)

*Number in parenthesis is power of 10.

$\phi(M_v) \equiv$ luminosity function of field stars.

$\phi_{MS}(\log M) \equiv$ present-day mass function (PDMF) of *main-sequence* field stars in the solar neighborhood is given by

$$\phi_{MS}(\log M) = \phi(M_v)\left|\frac{dM_v}{d\log M}\right| 2H(M_v) f_{MS}(M_v), \text{ where}$$

$H(M_v)$ is the scale height assuming that stars are distributed as $\exp(-|z|/H)$, where z is the distance measured perpendicular to the Galactic plane.

The factor $f_{MS}(M_v)$ gives the fraction of stars at a given magnitude that are on the main sequence.

T_{MS} = the main-sequence lifetime is given by

$$T_{MS} = \frac{\Delta X_{MS} ME}{L} \simeq 13 \times 10^9 (M/M_\odot)^{-2.5}\ \text{yr}, \quad M \lesssim 10\, M_\odot,$$

where

ΔX_{MS} = the mass fraction of hydrogen burned during the main-sequence phase, ~ 0.13.

E = energy released per gram in the nuclear fusion reaction, H → He, $\simeq 6.4 \times 10^{18}\ \text{erg g}^{-1}$.

L = total luminosity of star.

(Adapted from Shapiro, S. L. & Teukolsky, S. A., *Black Holes, White Dwarfs, and Neutron Stars*, John Wiley and Sons, 1983.)

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Star number densities ($\log N_m(pg)$ with galactic latitude [a])

m_{pg}	Galactic latitude									Mean
	0°	±5°	±10°	±20°	±30°	±40°	±50°	±60°	±90°	0°–90°
0.0		−4.0			−4.3			−4.4		−4.25
1.0		−3.4			−3.75			−3.9		−3.70
2.0		−2.83			−3.20			−3.3		−3.18
3.0		−2.32			−2.69			−2.8		−2.60
4.0	−1.75	−1.83	−1.88	−2.01	−2.16	−2.25	−2.30	−2.32	−2.40	−2.11
5.0	−1.28	−1.36	−1.43	−1.56	−1.69	−1.76	−1.80	−1.83	−1.89	−1.63
6.0	−0.82	−0.90	−0.97	−1.10	−1.22	−1.29	−1.34	−1.37	−1.42	−1.14
7.0	−0.39	−0.46	−0.53	−0.66	−0.77	−0.84	−0.89	−0.92	−0.97	−0.69
8.0	0.05	−0.01	−0.09	−0.22	−0.32	−0.40	−0.45	−0.48	−0.54	−0.25
9.0	0.52	0.43	0.35	0.22	0.12	0.04	−0.01	−0.06	−0.12	0.19
10.0	0.97	0.88	0.80	0.66	0.54	0.46	0.40	0.35	0.27	0.62
11.0	1.43	1.33	1.23	1.08	0.96	0.87	0.80	0.75	0.66	1.05
12.0	1.88	1.77	1.65	1.50	1.37	1.26	1.19	1.12	1.03	1.46
13.0	2.30	2.19	2.07	1.90	1.76	1.64	1.54	1.47	1.39	1.87
14.0	2.72	2.61	2.48	2.28	2.12	1.98	1.88	1.79	1.71	2.26
15.0	3.12	3.00	2.88	2.65	2.46	2.31	2.20	2.10	1.97	2.62
16.0	3.48	3.41	3.24	3.00	2.77	2.61	2.48	2.38	2.24	2.98
17.0	3.83	3.78	3.60	3.33	3.07	2.84	2.75	2.64	2.48	3.33
18.0	4.20	4.10	3.93	3.63	3.35	3.14	2.99	2.87	2.72	3.64
19.0	4.5	4.4	4.3	3.9	3.6	3.4	3.2	3.1	2.9	3.90
20.0	4.7	4.7	4.6	4.2	3.8	3.6	3.4	3.3	3.1	4.17
21.0	5.0	4.9	4.8	4.5	4.0	3.7	3.6	3.4	3.2	4.4

[a] $N_m(pg \approx B)$ = number of stars per square degree brighter than photographic magnitude m_{pg}.

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Star number densities (log N_m(vis) with galactic latitude[(b)]) (*cont.*)

	Galactic latitude									Mean
m_{vis}	0°	±5°	±10°	±20°	±30°	±40°	±50°	±60°	±90°	0°–90°
0.0		−3.9			−4.2			−4.3		−4.1
1.0		−3.3			−3.6			−3.7		−3.56
2.0		−2.7			−3.0			−3.1		−3.00
3.0		−2.14			−2.5			−2.6		−2.43
4.0	−1.55	−1.63	−1.68	−1.81	−1.96	−2.05	−2.10	−2.12	−2.20	−1.90
5.0	−1.08	−1.16	−1.23	−1.36	−1.49	−1.56	−1.60	−1.63	−1.69	−1.41
6.0	−0.60	−0.68	−0.75	−0.88	−1.00	−1.07	−1.12	−1.15	−1.20	−0.93
7.0	−0.16	−0.23	−0.30	−0.43	−0.54	−0.61	−0.66	−0.69	−0.74	−0.46
8.0	0.29	0.23	0.15	0.02	−0.08	−0.16	−0.21	−0.24	−0.30	0.00
9.0	0.78	0.69	0.61	0.48	0.38	0.30	0.25	0.20	0.14	0.45
10.0	1.25	1.16	1.08	0.94	0.82	0.74	0.68	0.63	0.55	0.91
11.0	1.73	1.63	1.53	1.38	1.26	1.17	1.10	1.05	0.96	1.34
12.0	2.18	2.07	1.93	1.80	1.67	1.57	1.49	1.42	1.33	1.76
13.0	2.60	2.49	2.37	2.20	2.08	1.94	1.84	1.77	1.69	2.17
14.0	3.02	2.91	2.78	2.60	2.44	2.28	2.18	2.09	2.01	2.56
15.0	3.42	3.30	3.18	2.95	2.78	2.61	2.50	2.40	2.27	2.94
16.0	3.78	3.71	3.54	3.30	3.09	2.91	2.78	2.68	2.54	3.29
17.0	4.13	4.08	3.90	3.60	3.37	3.19	3.05	2.94	2.78	3.64
18.0	4.50	4.40	4.23	3.93	3.65	3.44	3.29	3.17	3.02	3.95
19.0	4.8	4.7	4.6	4.2	3.9	3.7	3.5	3.4	3.2	4.20
20.0	5.0	5.0	4.9	4.5	4.1	3.9	3.7	3.6	3.4	4.5
21.0	5.3	5.2	5.1	4.8	4.3	4.1	3.9	3.7	3.5	4.7

[(b)] $N_m(\text{vis} \approx V)$ = number of stars per square degree brighter than visual magnitude m_{vis}.
(After Allen, C. W., *Astrophysical Quantities*, Athlone Press, 1973.)

Relative numbers of stars in each class (up to $V = 8.5$ in *HD Catalog*)

Sp	O	B	A	F	G	K	M
% stars	1	10	22	19	14	31	3

(After Allen, C. W., *Astrophysical Quantities*, Athlone Press, 1973.)

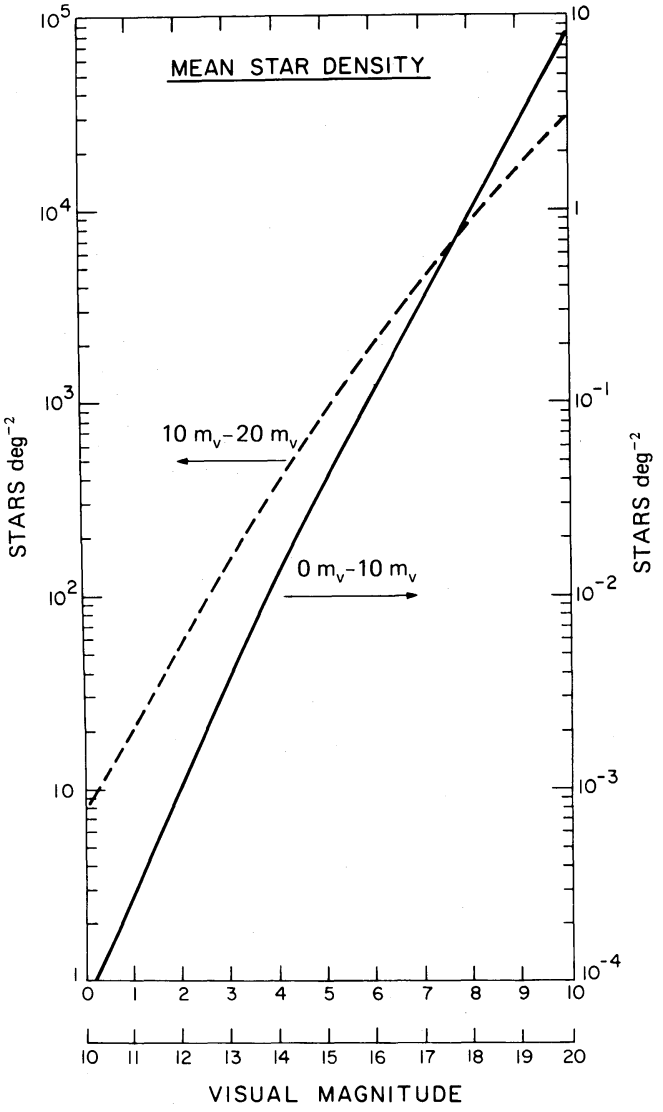
Integrated star light as a function of galactic latitude

	Star light (10th mag deg^{-2})			Star light (10th mag deg^{-2})			Star light (10th mag deg^{-2})	
Latitude	*pg*	*V*	Latitude	*pg*	*V*	Latitude	*pg*	*V*
0	180	372	20	54	105	60	21	38
5	123	247	30	37	71	70	19	35
10	88	176	40	29	54	80	18	34
15	69	138	50	24	43	90	18	34

Integrated star light from whole sky: 230 zero *pg* mag stars; 460 zero *V* mag stars.
Night sky total brightness (zenith, mean sky) $\approx 1(m_v = 22.5)$ star arcsec^{-2}.
(After Allen, C. W., *Astrophysical Quantities*, Athlone Press, 1973.)

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Mean star density vs. visual magnitude



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Star counts

A formula for estimating ($\sim 15\%$ accuracy) differential A and integral N star counts for a given galactic longitude l, latitude b, and apparent magnitudes V and B over the ranges $b \geqslant 20°$, $5 \leqslant m \leqslant 30$ for zero obscuration, $\Delta m = 0$, has been derived by Bahcall & Soniera (*Ap. J. Suppl.*, **44**, 73, 1980). (For non-zero obscuration, replace m by $m - \Delta m$, where $\Delta m_V = 0.15 \csc b$ and $\Delta m_B = 0.20 \csc b$.) The units of A are stars mag^{-1} deg^{-2} and of N are stars deg^{-2}.

$$D(l,b,m) = \frac{C_1 10^{\beta(m-m^*)}}{[1+10^{\alpha(m-m^*)}]^{\delta}} \frac{1}{[\sin b(1-\mu\cot b\cos l)]^{3-5\gamma}} + \frac{C_2 10^{\eta(m-m\dagger)}}{[1+10^{\kappa(m-m\dagger)}]^{\lambda}} \frac{1}{(1-\cos b\cos l)^{\sigma}},$$

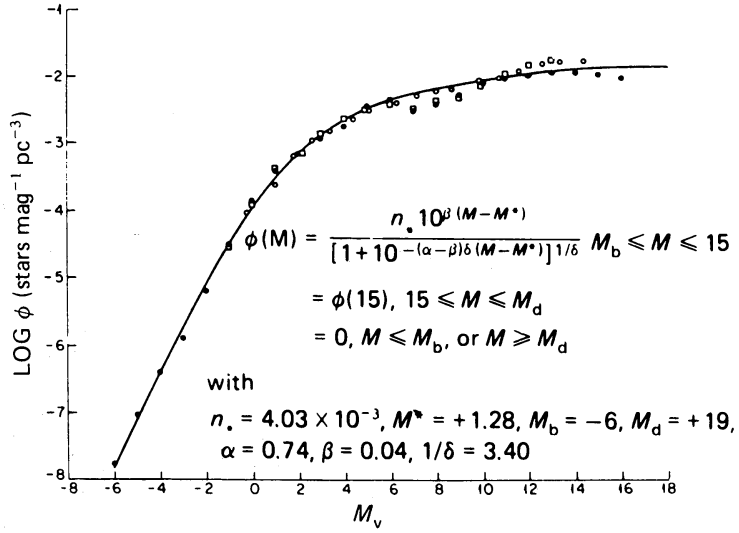
where the constants are $\sigma = 1.45 - 0.20\cos b\cos l$,

Constant	Range of m		
	$m \leqslant 12$	$12 < m < 20$	$m \geqslant 20$
μ	0.03	$0.0075(m-12)+0.03$	0.09
γ	0.36	$0.04(12-m)+0.36$	0.04

Star count	C_1	C_2	α	β	δ	m^*	κ	η	λ	$m\dagger$
$A_V = D$	200	400	−0.2	0.01	2	15	−0.26	0.065	1.5	17.5
$N_V = D$	925	1050	−0.132	0.035	3.0	15.75	−0.180	0.087	2.5	17.5
$A_B = D$	235	370	−0.227	0.0	1.5	17	−0.175	0.06	2.0	18
$N_B = D$	950	910	−0.124	0.027	3.1	16.60	−0.167	0.083	2.5	18

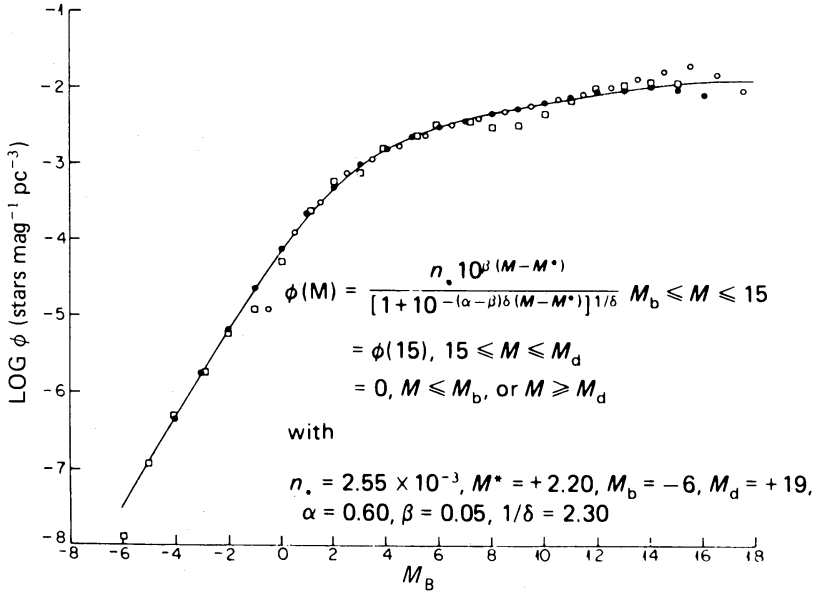
Luminosity functions

Local stellar luminosity function for the disk in the Visual band. The solid line is an analytic approximation. (Adapted from Bahcall, J. H. & Soneira, R. M., *Ap. J. Suppl.* **44**, 73, 1980.)



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Local stellar luminosity function for the disk in the Blue band. The solid line is an analytic approximation. (Adapted from Bahcall, J. N. & Soneira, R. M., *Ap. J. Suppl.*, **44**, 73, 1980.)



Parameters of the interstellar gas

Mean density ρ	3×10^{-24} g cm^{-3}
Typical particle density	
n (HI) in diffuse clouds	20 cm^{-3}
n (HI) between clouds	0.1 cm^{-3}
n_H in molecular clouds	$10^3 - 10^6$ cm^{-3}
Typical temperature T	
Diffuse HI clouds	80 K
HI between clouds	6000 K
HII photon ionized regions	8000 K
Coronal gas between clouds	6×10^5 K
Root-mean-square random cloud velocity	10 km s^{-1}
Isothermal sound speed C	
HI cloud at 80 K	0.7 km s^{-1}
HII gas at 8000 K	10 km s^{-1}
Magnetic field B	2.5×10^{-6} G
Effective thickness $2H$ of HI cloud layer	250 pc

(Adapted from Spitzer, L., *Physical Processes in the Interstellar Medium*, John Wiley and Sons, 1977.)

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Galaxies

Properties of the Galaxy

Type of galaxy:
- Hubble–van den Bergh system: Sb(−Sb$^+$)I–II
- de Vaucouleur's system: SAB(rs)bc II
- Morgan's system: gkS 7

M_v (mag): −20.5
Diameter: 23 kpc
(isophote: 25.0 mag (B) arcsec^{-2})
Period of rotation: 2.5×10^8 yr
Mass:
- Total mass: $1.8 \times 10^{11}\ M_\odot$
- Gas: $8 \times 10^9\ M_\odot$

Age: 1.2×10^{10} yr
Density in solar neighborhood:
- Stars: $0.05\ M_\odot$ pc^{-3}
- Total known: $0.08\ M_\odot$ pc^{-3}

Galactic nucleus:
- $R < 0.4$ pc $\approx 5 \times 10^6\ M_\odot$
- $R < 150$ pc $\approx 1 \times 10^9\ M_\odot$

Central bulge ($R < 2.5$ kpc): $\approx 4 \times 10^{10}\ M_\odot$

Luminosity of the galaxy:		*Energy density in the galaxy:*	
Radio	3×10^{38} erg s^{-1}	Starlight	0.7×10^{-12} erg cm^{-3}
Infrared	3×10^{41}	Turbulent gas	0.5×10^{-12}
Optical	3×10^{43}	Cosmic rays	2×10^{-12}
X-ray	$10^{39} - 10^{40}$	Magnetic field	2×10^{-12}
γ-ray (> 100 MeV)	5×10^{38}	2.7 K radiation	0.4×10^{-12}

Mass–luminosity ratio: M/L_{bol} (solar units) ≈ 10
Stellar radiation emission (solar neighborhood):
- $1.5 \times 10^{-3}(M_{bol} = 0)$ stars pc^{-3}
- 1.5×10^{-23} erg cm^{-3} s^{-1}

Stellar luminous radiation emission (solar neighborhood):
- $6.7 \times 10^{-4}(M_v = 0)$ stars pc^{-3}

Distance of the Sun from the galactic center:
- 8.7 ± 0.6 kpc (IAU, 1985)
- 7.1 ± 1.2 kpc (courtesy of M. Reid, Harvard/Smithsonian)

Height of Sun above galactic disk: 24±6 pc
Galactic coordinates of the nucleus: $l = -3'.34$, $b = -2'.75$
Equatorial coordinates of the nucleus:
- α 1950 = $17^h 42^m 29^s.3 \pm 0^s.15$
- δ 1950 = $-28°\ 59'\ 18'' \pm 3''$

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Name	α 2000	δ 2000	V (mag)	Dimension	Type	M_v	Distance (kpc)	Diameter (kpc)
Andromeda galaxy	$0^h42.^m7$	+41° 16′	3.4	178′ × 63′	Sb	−21.1	730	38
Milky Way	(17 45.6	−28 56)			Sb+:	−20.5	(8.5)	30:
Triangulum galaxy	1 33.9	+30 39	5.7	62 × 39	Sc	−18.9	900	16
Large Magellanic Cloud	5 23.6	−69 45	0.1	650 × 550	SBm	−18.5	50	9.5
IC 10	0 20.4	+59 18	10.3	5 × 4	Ir+:	−17.6	1300	1.9
Small Magellanic Cloud	0 52.7	−72 50	2.3	280 × 160	SBmp	−16.8	60	4.9
NGC 205	0 40.4	+41 41	8.0	17 × 10	E6:	−16.4	730	3.6
NGC 221	0 42.7	+40 52	8.2	8 × 6	E2	−16.4	730	1.7
NGC 6822	19 44.9	−14 48	9:	10 × 10	Ir+	−15.7	520	1.5
NGC 185	0 39.0	+48 20	9.2	12 × 10	dE0	−15.2	730	2.5
NGC 147	0 33.2	+48 30	9.3	13 × 8	dE4	−14.9	730	2.8
IC 1613	1 04.8	+2 07	9.3	12 × 11	Ir+	−14.8	740	2.6
WLM system	0 02.0	−15 28	10.9	12 × 4	Ir+	−14.7	1600	5.6
Leo A	9 59.4	+30 45	12.6	5 × 3	Ir+	−14.1	2300	3.3
Fornax dwarf galaxy	2 39.9	−34 32	8:	20: × 14:	dE3	−13.6	130	2.2:
IC 5152	22 02.9	−51 17	11:	5 × 3	Ir+	−13.5	1500	2.2
Pegasus dwarf galaxy	23 28.6	+14 45	12.0	5 × 3	Ir+	−13.4	1300	1.9
Sculptor dwarf galaxy	0 59.9	−33 42	10:		dE3	−11.7	85	1.5:
Leo I	10 08.4	+12 18	9.8	11 × 8	dE3	−11.0	230	0.7
Andromeda I	0 45.7	+38 00	13.2		dE0	−11:	730	
Andromeda II	1 16.4	+33 27	13:		dE0	−11:	730	
Andromeda III	0 35.4	+36 31	13:		dE2	−11:	730	
Aquarius dwarf galaxy	20 46.9	−12 51			Ir	−11:	1500	
Sagittarius dwarf galaxy	19 30.0	−17 41	15:		Ir−	−10:	1100	
Leo II	11 13.5	+22 10	11.5	15 × 13	dE0	−9.4	230	1.0
Ursa Minor dwarf galaxy	15 08.8	+67 12	12:	27 × 16	dE6	−8.8	75	0.6
Draco dwarf galaxy	17 20.2	+57 55	11:	34 × 19	dE3	−8.6:	80	0.8
LGS 3	1 03.8	+21 53	15:	2	Ir	−8.5:	900	0.5
Carina dwarf galaxy	6 41.6	−50 58			dE		170	

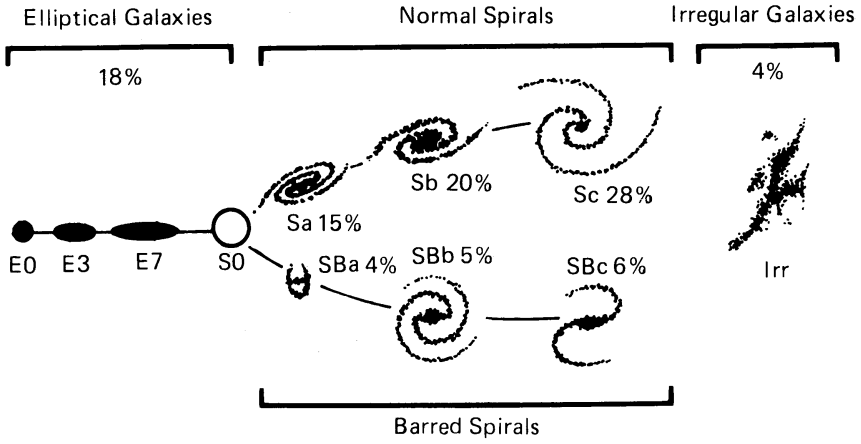
: denotes approximate value

(Adapted from *Sky Catalogue 2000.0*, Vol. 2, Sky Publishing Corp., 1985.)

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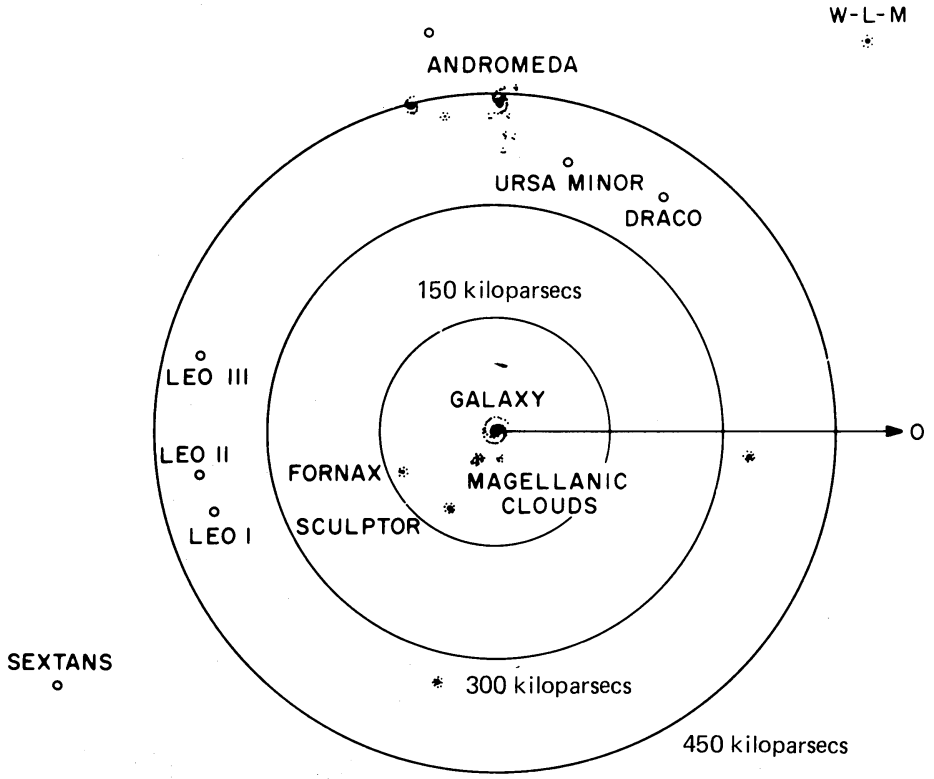
Hubble's classification of galaxies

The number n behind the symbol E characterizes the ellipticity: $n = 10(a - b)/a$, where a and b are the major and minor diameters of the ellipse. The letters a, b, c following S and SB characterize the increasing degree of opening of the spiral arms. (Adapted from *Landolt–Börnstein, Astronomy and Astrophysics*, (1982)



Nearby extragalactic objects

Nearby extragalactic objects with our galaxy in the central position. (Adapted from Roach, F. E. & Gordon, J. L., *The Light of the Night Sky*, D. Reidel Publishing Co., 1973.)



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Selected brighter galaxies ($V < 9$) (local group is excluded)

Galaxy	NGC IC	Type	l^{II} (°)	b^{II} (°)	Diameter Ang. (′)	Diameter Lin. (kpc)	$\varepsilon^{(a)}$	Distance (Mpc)	V	$B-V$	M_v	Mass ($10^{11}\,M_\odot$)
	55	Sc	333	−76	25	12	0.9	2.3	7.2		−19.9	0.32
	253	Sc	75	−89	22	13	0.8	2.4	7		−20	1.0
	2403	Sc	151	+28	18	11	0.4	3.2	8.4	0.5	−19.2	0.13
M81	3031	Sb	142	+41	20	16	0.5	3.2	6.9	1.0	−20.9	1.6
M82	3034	Ir II	141	+41	8	7	0.7	3	8.2	0.9	−19.6	0.32
	3115	E7	247	+37	4	5	0.7	4	9.1	1.0	−19.3	0.79
M106	4258	Sb	138	+69	15	17	0.6	4.0	8.2	0.8	−20.1	1.0
M87	4486	E1	283	+75	4	13	0.2	13	8.7	1.0	−21.7	40.0
M104 Sombrero	4594	Sa	298	+51	6	8	0.3	12	8.1	1.0	−22	5.0
M94	4736	Sb	123	+76	7	10	0.2	4.5	8.2	0.8	−20.4	1.0
M64	4826	Sb	316	+84	8	12	0.5	3.9	8.4	0.9	−19.7	0.79
	4945	Sb	305	+13	12	14	0.8	4.0	7		−21	
M63	5055	Sb	105	+74	10	15	0.5	4.6	8.4	0.9	−20.0	0.01
Cen A	5128	E0p	310	+19	14	15	0.2	4.4	7		−20	2.0
M51 Whirlpool	5194	Sc	105	+69	9	9	0.4	3.8	8.2	0.6	−19.7	0.79
M83	5236	SBc	315	+32	10	12	0.2	3.2	7.2	0.7	−20.6	
M101 Pinwheel	5457	Sc	102	+60	20	23	0.0	3.8	7.5	0.6	−20.3	1.6
	7793	Sd	4	−77	6	4	0.4	2.6	8.8		−18.4	

[a] ε = ellipticity = $(a-b)/a$, where a and b are the major and minor diameters, respectively.
(After Allen, C. W., *Astrophysical Quantities*, The Athlone Press, 1973.)

Named galaxies

Name	α 2000	δ 2000
Andromeda galaxy = M31 = NGC 224	$00^h42^m.7$	+41° 16′
Andromeda I	00 45.7	+38 00
Andromeda II	01 16.3	+33 25
Andromeda III	00 35.3	+36 30
Andromeda IV	00 42.5	+40 34
BL Lac	22 02.7	+42 17
Capricorn dwarf = Pal 13†	21 46.8	−21 15
Caraffe galaxy	04 28.0	−47 54
Carina dwarf	06 46.3	−51 03
Cartwheel galaxy	00 37.4	−33 45
Centaurus A = NGC 5128 = Arp 135	13 25.4	−43 02
Circinus galaxy	14 13.2	−65 20
Copeland Septet = NGC 3745/54 = Arp 320	11 37.7	+22 01
Cygnus A	19 59.4	+40 44
Draco dwarf = DDO 208	17 20.0	+57 55
Fath 703	15 13.8	−15 28
Fornax A = NGC 1316	03 22.7	−37 12
Fornax dwarf	02 39.9	−34 31
Fourcade–Figueroa object	13 35.2	−33 53
GR8 = DDO 155	12 58.7	+14 13
Hardcastle Nebula	13 13.0	−32 42
Hercules A	16 51.2	+05 01
Holmberg I = DDO 63	09 40.5	+71 12
Holmberg II = DDO 50 = Arp 268	08 19.0	+70 43
Holmberg III	09 14.9	+74 14
Holmberg IV = DDO 185	13 54.6	+53 54
Holmberg V	13 40.7	+54 20
Holmberg VI = NGC 1325 A	03 24.8	−21 20
Holmberg VII = DDO 137	12 34.7	+06 18
Holmberg VIII = DDO 166	13 13.3	+36 13
Holmberg IX = DDO 66	09 57.6	+69 03
Hydra A	09 18.1	−12 06
Large Magellanic Cloud	05 23.5	−69 45
Leo I = Harrington–Wilson No. 1 = Regulus Dwarf = DDO 74	10 08.5	+12 18
Leo II = Harrington–Wilson No. 2 = Leo B = DDO 93	11 13.5	+22 10
Leo A = Leo III = DDO 69	09 59.4	+30 45
Lindsay–Shapley ring	06 43.1	−74 14
Maffei I	02 36.3	+59 39
Maffei II	02 41.9	+59 36
Mayall's Object = Arp 148 = VV 32	11 03.9	+40 51
Mice = NGC 4676 = Arp 242	12 47.1	+30 38
Pegasus dwarf = DDO 216	23 28.5	+14 44
Perseus A = NGC 1275	03 19.8	+41 31
Reticulum dwarf	04 36.2	−58 50
Reinmuth 80 = NGC 4517 A	01 00.0	−33 42

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Named galaxies *(cont.)*

Name	α 2000	δ 2000
Seashell galaxy	13^h47^m3	−30°25′
Serpens dwarf	15 16.0	−00 08
Seyfert's Sextet = NGC 6027 A–D	15 59.2	+20 45
Sextans A = DDO 75	10 11.1	−04 43
Sextans B = DDO 70	10 00.0	+05 20
Sextans C	10 05.5	+00 04
Small Magellanic Cloud	00 52.8	−72 50
Sombrero galaxy = M104 = NGC 4594	12 40.2	−11 37
Stephan's Quintet = NGC 7317−20 = Arp 319	22 36.0	+33 58
Triangulum galaxy = M33 = NGC 598	01 34.5	+30 39
Ursa Minor dwarf = DDO 199	15 08.8	+67 12
Virgo A = M87 = NGC 4486 = Arp 152	12 30.8	+12 23
Whirlpool galaxy = M51 = NGC 5194	13 29.9	+47 12
Wild's Triplet = Arp 248	11 46.8	−03 50
Wolf–Lundmark–Melotte object = DDO 221	00 02.0	−15 27
Zwicky No. 2 = DDO 105	11 58.5	+38 04
Zwicky's Triplet = Arp 103	16 49.5	+45 28

† Probably a distant globular cluster.
(Adapted from Landolt-Börnstein, *Astronomy and Astrophysics*, VI/2C, Springer-Verlag, 1982.)

Representative active galactic nuclei (AGNs)

Object	α 1950	δ 1950	z	m_v
QUASARS				
Q 0002−422	$00^h02^m16^s$	−42° 14′	2.758	17.4
PHL 938	00 58 20	01 55	1.95	17.2
4C 25.05	01 23 57	25 44	2.34	17.5
PHL 1093	01 37 23	01 17	0.262	17.1
PHL 1194	01 48 52	09 03	0.298	17.5
RN 8	02 10 49	86 05	0.184	19.0
Q 0242−410	02 42 02	−41 04	2.214	18.1
Q 0324−407	03 24 29	−40 47	3.056	17.6
PKS 0424−13	04 24 48	−13 10	2.16	17.5
Q 0453−423	04 53 48	−42 21	2.661	17.3
Q 0551−366	05 51 02	−36 38	2.307	17.0
OH 471	06 42 53	44 55	3.39	18.5
PKS 0736+01	07 36 43	01 44	0.192	16.5
4C 05.34	08 05 19	04 41	2.86	18.2
0938+119	09 38 32	11 59	3.19	19.0
3C 232	09 55 25	32 38	0.533	15.8
Ton 490	10 11 06	25 04	1.63	15.4
PKS 1217+02	12 17 39	02 20	0.240	16.5
3C 273	12 26 33	02 20	0.158	12.8
Q 1246−057	12 46 29	−05 43	2.212	17.0
B 340	13 04 48	34 40	0.184	17.0
1331+170	13 31 10	17 04	2.08	16.0

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Representative active galactic nuclei (*cont.*)

Object	α 1950	δ 1950	z	m_v
3C 323.1	$15^h45^m31^s$	21°01′	0.264	16.7
4C 29.50	17 02 11	29 51	1.92	19.1
3C 351	17 04 03	60 49	0.371	15.3
Q 2116−358	21 16 22	−35 49	2.341	17.0
PKS 2135−14	21 35 01	−14 46	0.200	15.5
2256+017	22 56 25	01 48	2.66	18.5
SEYFERT GALAXIES				
Seyfert 1 galaxies				
Mrk 335	00 03 45	19 55	0.025	14.2
I Zw 1	00 51 00	12 25	0.061	14.3
Mrk 376	07 10 36	45 47	0.056	16.0
Mrk 79	07 38 47	49 56	0.020	13.4
Mrk 10	07 43 07	61 03	0.029	15.0
Mrk 110	09 21 44	52 30	0.036	16.1
NGC 3227	10 20 47	20 07	0.0033	13.5
NGC 3516	11 03 24	72 50	0.0093	13.1
NGC 4151	12 08 01	39 41	0.0033	12.0
Mrk 236	12 58 18	61 55	0.052	17.0
Mrk 279	13 51 52	69 33	0.0307	15.4
Mrk 290	15 34 45	58 04	0.0308	15.6
Mrk 486	15 35 21	54 43	0.039	15.0
Mrk 509	20 41 26	−10 54	0.0355	13.0
NGC 7469	23 00 44	08 36	0.0167	13.6
Mrk 541	23 53 30	07 15	0.041	15.5
Seyfert 2 galaxies				
Mrk 1	01 13 19	32 50	0.016	16.6
NGC 1068	02 40 07	−00 14	0.003 63	10.5
Mrk 612	03 21 10	−03 19	0.020 22	16.5
III Zw 55	03 38 38	−01 28	0.0246	14.0
Mrk 3	06 09 48	71 03	0.0137	13.8
Mrk 78	07 37 56	65 18	0.0375	15.6
Mrk 622	08 04 21	39 09	0.022 83	15.6
Mrk 34	10 30 52	60 17	0.051	14.8
Mrk 176	11 29 54	53 14	0.0269	15.5
Mrk 270	13 39 41	56 55	0.009	15.0
Mrk 463E	13 53 40	18 37	0.0505	16.0
Mrk 533	23 25 24	08 30	0.028 73	16.0
BL LAC OBJECTS				
PKS 0215+015	02 15 13	01 31		18.3
AO 0235+164	02 35 53	16 24		15.5
PKS 0521−365	05 21 14	−36 30	0.55	15.0
PKS 0548−323	05 48 50	−32 17	0.069	15.5
OJ 287	08 51 57	20 18		14.0
4C 22.25	09 57 34	22 48		18.0
Mkn 421	11 01 41	38 29	0.308	13.5
Mkn 180	11 33 30	70 25	0.0458	15.0
AP Lib	15 14 45	−24 11	0.049	15.0
Mkn 501	16 52 12	39 50	0.034	13.8
BL Lac	22 00 40	42 02	0.0688	14.5

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Representative active galactic nuclei *(cont.)*

Object	α 1950	δ 1950	z	m_v
RADIO GALAXIES				
BLRGs				
3C 109	$04^h\,10^m55^s$	11° 15′	0.306	18.0
3C 120	04 30 32	05 15	0.033	14.6
3C 227	09 45 07	07 39	0.0855	16.3
3C 234	09 58 57	29 02	0.1846	17.1
3C 287.1	13 29 04	25 24	0.2156	18.5
PKS 1417 − 19	14 17 02	−19 15	0.1195	17.5
4C 35.37	15 31 45	35 52	0.1565	17.5
3C 332	16 14 44	30 09	0.1515	16.0
3C 381	18 32 28	47 24	0.1614	17.5
3C 382	18 33 12	32 39	0.0586	15.4
3C 390.3	18 45 38.8	79 43	0.0569	15.4
3C 445	22 21 15	−02 21	0.0568	15.8
NLRGs				
3C 33	01 06 14	13 04	0.0595	16.3
3C 98	03 56 10	10 18	0.0306	14.8
3C 178	07 22 33	−09 30	0.0079	16.1
3C 184.1	07 32 20	70 20	0.1182	17
3C 192	08 02 38	24 16	0.0598	16.2
3C 327	15 59 56	02 06	0.1039	16.3
3C 433	21 21 30	24 52	0.1025	15.7
3C 452	22 43 33	39 25	0.082	16.6
PKS 2322 − 12	23 22 43	−12 24	0.0821	15.8
LINERS				
Mrk 1158	01 32 07	34 47	0.0151	16.2
NGC 1052	02 38 37	−08 28	0.0048	13.2
Ark 160	08 17 52	19 31	0.019	17.6
NGC 2841	09 18 35	51 11	0.0022	13.5
NGC 2911	09 31 05	10 23	0.0106	15.3
NGC 3031	09 51 30	69 18	−0.0001	12.4
NGC 3758	11 33 48	21 52	0.0296	16.6
NGC 3998	11 55 20	55 44	0.0038	13.3
NGC 4036	11 58 54	62 10	0.0046	14.0
NGC 4278	12 17 36	29 34	0.0022	13.6
NGC 5005	13 08 37	37 19	0.0033	14.1
NGC 5077	13 16 53	−12 24	0.0094	14.4
NGC 5371	13 53 33	40 42	0.0086	15.0
Mrk 298	16 03 18	17 56	0.0345	16.2
Mrk 700	17 01 21	31 31	0.034	15
NGC 6764	19 07 01	50 51	0.008	15.5

Redshift $z = \Delta\lambda/\lambda$.
m_v = approximate nuclear visual magnitude.

Luminosity distance $D_L(q_0 = 0) = \dfrac{cz}{H_0}(1 + 0.5z)$. For other values of q_0 see chapter on Relativity.
(Adapted from Landolt–Börnstein, *Astronomy and Astrophysics*, V1/2C, Springer-Verlag, 1982.)

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Objects with large redshifts

Object	α 1950	δ 1950	z (em)	V
1208 + 1011	$12^h08^m23^s.73$	+10°11′ 07″.9	3.80	
PKS 2000 − 330	20 00 12.94	−33 00 14.6	3.78	19.0
0055 − 2659	00 55 32.46	−25 29 26.0	3.67	17.1
DHM 0054 − 284	00 53 59.8	−28 24 45	3.61	19.55
OQ 172	14 42 50.48	10 11 12.2	3.53	17.78
1159 + 1223	11 59 14.23	+12 23 11.9	3.51	17.5
222738 − 3928	22 27 38	−39 28 32	3.45	16.8
OH 471	06 42 53.02	−44 54 31.1	3.40	18.49
0042 − 2627	00 42 06.22	−26 27 42.9	3.30	18.5
OX − 146			3.27	
2016 + 112†	20 16 55	11 17 46	3.27	22.5
OS 023			3.21	
024929 − 1826	02 49 29.8	−18 26 21	3.21	18.6
OQ 004			3.20	
024925 − 2212	02 49 25.5	−22 12 37	3.20	18.4
Q 0938 + 119	09 38 31.75	11 59 12.6	3.19	19

† Gravitational lens.
Note added in proof: Over 20 quasars are now known with redshifts greater than 3.5 (see *Sky & Telescope*, **75**, 12, 1988).

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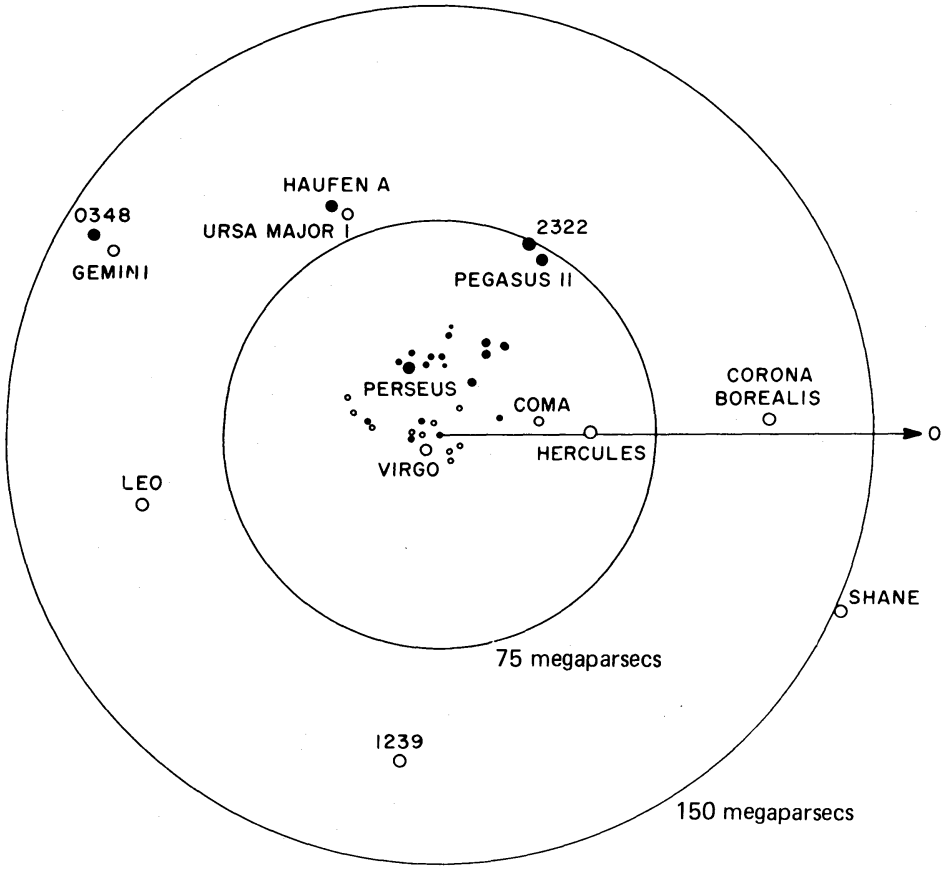
Name	Abell No.	α 2000	δ 2000	Diameter (°)	*RV* (km s^{-1})	RS type	NGC	Radio source	Notes
Haufen A	151	$1^h08^m.9$	−15°25′		15 800	cD			
	194	1 25.6	−1 30	0.3	5320	L	541, 5, 7	3C 40	In Perseus supercluster
	400	2 57.6	+6 02		7200	I		3C 75	
Perseus	426	3 18.6	+41 32	4	5460	L	1275	3C 84	In Perseus supercluster; XRS
Fornax II		3 28	−20 45	7	1560		1232		
Fornax I		3 32	−35 20	7	1500		1316	For A	
Gemini	568	7 07.6	+35 03	0.5	23 400	C			
Cancer		8 21	+20 56	3	4800		2563		
Hydra II		8 58	+3 09		60 900				
Leo	1020	10 27.8	+10 25	0.6	19 500				Also Abell 1016?
Hydra I	1060	10 36.9	−27 32		3000	C	3309, 11		XRS
Ursa Major II		10 58	+56 46	0.2	41 000				
Leo A	1185	11 10.9	+28 41		10 500	C	3550		
	1367	11 44.5	+19 50		6150	F	3842, 62	3C 264	In Coma supercluster; XRS
Ursa Major I	1377	11 47.1	+55 44	0.7	15 300	B			
Virgo		12 30	+12 23	12	1200		4472, 86	Vir A	In Local supercluster; XRS
Centaurus		12 50	−41 18	2	3200		4696	PKS	XRS
Coma	1656	12 59.8	+27 59	4	6650	B	4889		In Coma supercluster; XRS
Boötes	1930	14 33	+31 33	0.3	39 300				
Corona Borealis	2065	15 22.7	+27 43	0.5	21 600	C			
Hercules	2151	16 05.2	+17 45	1.7	11 200	F	6040, 47	4C+17.66	In Hercules supercluster; XRS
	2152	16 05.4	+16 27		11 500	~I			In Hercules supercluster
	2197	16 28.2	+40 54		9100	L	6173		In Hercules supercluster
	2199	16 28.6	+39 31	0.2	9200	cD	6166	3C 338	In Hercules supercluster; XRS
Pegasus II		23 10	+7 36	2	12 700		7720	4C+07.61	
Pegasus I		23 22	+9 02	1	4000		7619	PKS	

$z = RV/3.00 \times 10^5$; distance (Mpc) $= RV/50$ ($H_0 = 50$ km s^{-1} Mpc^{-1}).
(Adapted from *Sky Catalogue 2000.0*, Vol. 2, Sky Publishing Corp., 1985.)

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Prominent clusters of galaxies (*cont.*)

Extragalactic systems within about 150 megaparsecs.



(Adapted from Roach, F. E. & Gordon, J. L. The Light of the Night Sky, D. Reidel Publishing Co., 1973.)

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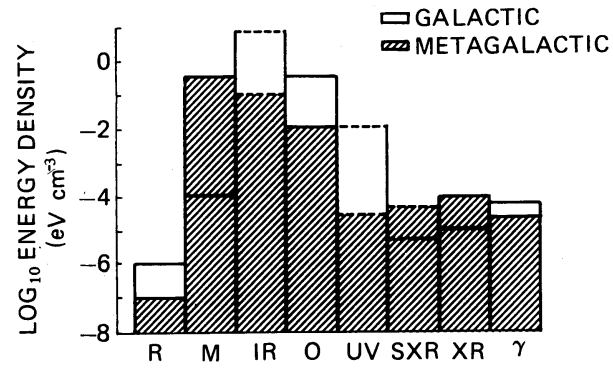
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Energy content of constituents of space

Constituent	Energy content (average all space including intergalactic space)	Primary sources
A. Photons:		
1. Infraradio	?	?
2. Radio and microwave (exclude 3 K radiation)	1 μeV cm^{-3}	Galaxy, radio galaxies, quasars
3. 3 K radiation	0.4 eV cm^{-3}	Big bang
4. Infrared	? may be > 3 K radiation	Seyfert galaxies, quasars, N galaxies
5. Visible light	0.01 eV cm^{-3} (0.3 eV cm^{-3} in galaxy)	Stars in normal galaxies
6. Soft X-rays (< 1 keV)	50–100 μeV cm^{-3}	ISM and discrete sources
7. Hard X-rays (1–500 keV)	100 μeV cm^{-3}	Hot plasma; inverse Compton scattering of fast electrons with background radiation; discrete sources (quasars)
8. Gamma rays ($E > 35$ MeV)	2 μeV cm^{-3}	Uncertain, probably active galaxies
B. Magnetic fields	0.001 eV cm^{-3}	?
C. Cosmic rays and fast electrons	100 μeV cm^{-3}	Radio galaxies, quasars, supernovae in normal galaxies
D. Neutrinos	0.1 eV cm^{-3} (?)	Big bang
E. Gravitons	0.1 eV cm^{-3} (?)	Big bang
F. Matter (ρc^2) ($\rho = 2 \times 10^{-31}$ g cm^{-3})	100 eV cm^{-3}	Galaxies

Energy density of cosmic photons

R = radio — UV = ultraviolet
M = microwave — SXR = soft X-ray
IR = infrared — XR = X-ray
O = optical — γ = gamma ray



'Adapted from Rose, W. K., *Astrophysics*, Holt, Rinehart, and Winston, Inc., 1973.)

Mass–radius–density data for astronomical objects

Class of objects	Examples	log M (g)	log R (cm)	log ρ (g cm^{-3})	log ϕ†
Neutron stars		33.16	5.93	14.75	−0.6?
		32.54	7.44	9.60	−2.5
White dwarfs	L930−80	33.45	8.3:	7.93	−2.7
	αCMaB	33.30	8.77	6.37	−3.2
	vM2	32.90	9.05	4.13	−5.0
Main sequence stars	dM8	32.2	9.95	1.76	−5.6
	Sun	33.30	10.84	0.15	−5.5
	A0	33.85	11.25	−0.55	−4.7
	O5	34.9	12.1:	−2.0	−5.0:
Supergiant stars	F0	34.4	12.65	−4.2	−6.1
	K0	34.4	13.15	−5.7	−6.6
	M2	34.7	13.75	−7.2	−6.9
Protostars	IR	35.3?	16.2?	−13.9?	−8.7?
Compact dwarf elliptical galaxies	M32, core	41.0	19.5?	−18.1	−6.3
	M32, effective	42.5	20.65	−20.0	−5.9
	N4486-B	43.4	20.5	−18.75	−5.0
Spiral galaxies	LMC	43.2	21.75	−22.65	−6.3
	M33	43.5	21.8	−22.5	−6.1
	M31	44.6	22.3	−22.9	−5.5
Giant elliptical galaxies	N3379	44.3	22.0	−22.35	−5.6
	N4486	45.5	22.4	−22.3	−4.7
Compact groups of galaxies	Stephan	45.5	22.6:	−23.1:	−4.7
Small groups of spirals	Sculptor	46.2	24.1	−26.7	−5.7
Dense groups of ellipticals	Virgo E, core Fornax I	46.5	23.7	−25.2	−5.0
Small clouds of galaxies	Virgo S Ursa Major	47.0	24.3	−26.5	−5.1
Small clusters of galaxies	Virgo F	47.2	24.3	−26.3	−4.9
Large clusters of ellipticals	Coma	48.3	24.6	−26.1	−4.9
Superclusters	Local	48.7:	25.5:	−28.4:	−4.7
HMS sample to $m \simeq 12.5$			26.0:	−29.6	−4.6
Lick Observatory counts to $m \simeq 19.0$			26.8	−30.5	−4.1

: denotes approximate value; ? denotes large uncertainty

† The filling factor $\phi = \rho/\rho_m$, where $\rho_m = 3c^2/8\pi GR_m^2$; $R_m = 2GM/c^2$.

(Adapted from de Vaucouleurs, G., *Science*, **167**, 1203, 1970.)

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The Messier catalog

M	NGC	α 2000	δ 2000	Const.	Dim. (′)	V (mag)	Type	Common name
1	1952	$5^h34.^m5$	+22°01′	Tau	6 × 4	8.4:	Di	Crab Nebula
2	7089	21 33.5	−0 49	Aqr	13	6.5	Gb	
3	5272	13 42.2	+28 23	CVn	16	6.4	Gb	
4	6121	16 23.6	−26 32	Sco	26	5.9	Gb	
5	5904	15 18.6	+2 05	Ser	17	5.8	Gb	
6	6405	17 40.1	−32 13	Sco	15	4.2	OC	
7	6475	17 53.9	−34 49	Sco	80	3.3	OC	
8	6523	18 03.8	−24 23	Sgr	90 × 40	5.8:	Di	Lagoon Nebula
9	6333	17 19.2	−18 31	Oph	9	7.9:	Gb	
10	6254	16 57.1	−4 06	Oph	15	6.6	Gb	
11	6705	18 51.1	−6 16	Sct	14	5.8	OC	
12	6218	16 47.2	−1 57	Oph	14	6.6	Gb	
13	6205	16 41.7	+36 28	Her	17	5.9	Gb	Hercules Cluster
14	6402	17 37.6	−3 15	Oph	12	7.6	Gb	
15	7078	21 30.0	+12 10	Peg	12	6.4	Gb	
16	6611	18 18.8	−13 47	Ser	7	6.0	OC	
17	6618	18 20.8	−16 11	Sgr	46 × 37	7:	Di	Omega Nebula
18	6613	18 19.9	−17 08	Sgr	9	6.9	OC	
19	6273	17 02.6	−26 16	Oph	14	7.2	Gb	
20	6514	18 02.6	−23 02	Sgr	29 × 27	8.5:	Di	Trifid Nebula
21	6531	18 04.6	−22 30	Sgr	13	5.9	OC	
22	6656	18 36.4	−23 54	Sgr	24	5.1	Gb	
23	6494	17 56.8	−19 01	Sgr	27	5.5	OC	
24		18 16.9	−18 29	Sgr	90	4.5:		
25	IC 4725	18 31.6	−19 15	Sgr	32	4.6	OC	
26	6694	18 45.2	−9 24	Sct	15	8.0	OC	
27	6853	19 59.6	+22 43	Vul	8 × 4	8.1:	Pl	Dumbbell Nebula
28	6626	18 24.5	−24 52	Sgr	11	6.9:	Gb	
29	6913	20 23.9	+38 32	Cyg	7	6.6	OC	
30	7099	21 40.4	−23 11	Cap	11	7.5	Gb	
31	224	0 42.7	+41 16	And	178 × 63	3.4	S	Andromeda Galaxy
32	221	0 42.7	+40 52	And	8 × 6	8.2	E	
33	598	1 33.9	+30 39	Tri	62 × 39	5.7	S	
34	1039	2 42.0	+42 47	Per	35	5.2	OC	
35	2168	6 08.9	+24 20	Gem	28	5.1	OC	
36	1960	5 36.1	+34 08	Aur	12	6.0	OC	
37	2099	5 52.4	+32 33	Aur	24	5.6	OC	
38	1912	5 28.7	+35 50	Aur	21	6.4	OC	

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The Messier catalog (*cont.*)

M	NGC	α 2000	δ 2000	Const.	Dim. (′)	*V* (mag)	Type	Common name
39	7092	$21^h32^m.2$	+48° 26′	Cyg	32	4.6	OC	
40		12 22.4	+58 05	UMa		8:		
41	2287	6 47.0	−20 44	CMa	38	4.5	OC	
42	1976	5 35.4	−5 27	Ori	66 × 60	4:	Di	Orion Nebula
43	1982	5 35.6	−5 16	Ori	20 × 15	9:	Di	
44	2632	8 40.1	+19 59	Cnc	95	3.1	OC	Praesepe
45		3 47.0	+24 07	Tau	110	1.2	OC	Pleiades
46	2437	7 41.8	−14 49	Pup	27	6.1	OC	
47	2422	7 36.6	−14 30	Pup	30	4.4	OC	
48	2548	8 13.8	−5 48	Hya	54	5.8	OC	
49	4472	12 29.8	+8 00	Vir	9 × 7	8.4	E	
50	2323	7 03.2	−8 20	Mon	16	5.9	OC	
51	5194−5	13 29.9	+47 12	CVn	11 × 8	8.1	S	Whirlpool Galaxy
52	7654	23 24.2	+61 35	Cas	13	6.9	OC	
53	5024	13 12.9	+18 10	Com	13	7.7	Gb	
54	6715	18 55.1	−30 29	Sgr	9	7.7	Gb	
55	6809	19 40.0	−30 58	Sgr	19	7.0	Gb	
56	6779	19 16.6	+30 11	Lyr	7	8.2	Gb	
57	6720	18 53.6	+33 02	Lyr	1	9.0:	Pl	Ring Nebula
58	4579	12 37.7	+11 49	Vir	5 × 4	9.8	S	
59	4621	12 42.0	+11 39	Vir	5 × 3	9.8	E	
60	4649	12 43.7	+11 33	Vir	7 × 6	8.8	E	
61	4303	12 21.9	+4 28	Vir	6 × 5	9.7	S	
62	6266	17 01.2	−30 07	Oph	14	6.6	Gb	
63	5055	13 15.8	+42 02	CVn	12 × 8	8.6	S	
64	4826	12 56.7	+21 41	Com	9 × 5	8.5	S	
65	3623	11 18.9	+13 05	Leo	10 × 3	9.3	S	
66	3627	11 20.2	+12 59	Leo	9 × 4	9.0	S	
67	2682	8 50.4	+11 49	Cnc	30	6.9	OC	
68	4590	12 39.5	−26 45	Hya	12	8.2	Gb	
69	6637	18 31.4	−32 21	Sgr	7	7.7	Gb	
70	6681	18 43.2	−32 18	Sgr	8	8.1	Gb	
71	6838	19 53.8	+18 47	Sge	7	8.3	Gb	
72	6981	20 53.5	−12 32	Aqr	6	9.4	Gb	
73	6994	20 58.9	−12 38	Aqr				
74	628	1 36.7	+15 47	Psc	10 × 9	9.2	S	
75	6864	20 06.1	−21 55	Sgr	6	8.6	Gb	
76	650−1	1 42.4	+51 34	Per	2 × 1	11.5:	Pl	
77	1068	2 42.7	−0 01	Cet	7 × 6	8.8	S	
78	2068	5 46.7	+0 03	Ori	8 × 6	8:	Di	
79	1904	5 24.5	−24 33	Lep	9	8.0	Gb	
80	6093	16 17.0	−22 59	Sco	9	7.2	Gb	

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The Messier catalog (*cont.*)

M	NGC	α 2000	δ 2000	Const.	Dim. (′)	*V* (mag)	Type	Common name
81	3031	$9^h55.^m6$	+69°04′	UMa	26 × 14	6.8	S	
82	3034	9 55.8	+69 41	UMa	11 × 5	8.4	Ir	
83	5236	13 37.0	−29 52	Hya	11 × 10	7.6:	S	
84	4374	12 25.1	+12 53	Vir	5 × 4	9.3	E	
85	4382	12 25.4	+18 11	Com	7 × 5	9.2	E	
86	4406	12 26.2	+12 57	Vir	7 × 6	9.2	E	
87	4486	12 30.8	+12 24	Vir	7	8.6	E	Virgo A
88	4501	12 32.0	+14 25	Com	7 × 4	9.5	S	
89	4552	12 35.7	+12 33	Vir	4	9.8	E	
90	4569	12 36.8	+13 10	Vir	10 × 5	9.5	S	
91	4548	12 35.4	+14 30	Com	5 × 4	10.2	S	
92	6341	17 17.1	+43 08	Her	11	6.5	Gb	
93	2447	7 44.6	−23 52	Pup	22	6.2:	OC	
94	4736	12 50.9	+41 07	CVn	11 × 9	8.1	S	
95	3351	10 44.0	+11 42	Leo	7 × 5	9.7	S	
96	3368	10 46.8	+11 49	Leo	7 × 5	9.2	S	
97	3587	11 14.8	+55 01	UMa	3	11.2:	Pl	Owl Nebula
98	4192	12 13.8	+14 54	Com	10 × 3	10.1	S	
99	4254	12 18.8	+14 25	Com	5	9.8	S	
100	4321	12 22.9	+15 49	Com	7 × 6	9.4	S	
101	5457	14 03.2	+54 21	UMa	27 × 26	7.7	S	
102								M101 reobservation
103	581	1 33.2	+60 42	Cas	6	7.4:	OC	
104	4594	12 40.0	−11 37	Vir	9 × 4	8.3	S	Sombrero Galaxy
105	3379	10 47.8	+12 35	Leo	4 × 4	9.3	E	
106	4258	12 19.0	+47 18	CVn	18 × 8	8.3	S	
107	6171	16 32.5	−13 03	Oph	10	8.1	Gb	
108	3556	11 11.5	+55 40	UMa	8 × 2	10.0	S	
109	3992	11 57.6	+53 23	UMa	8 × 5	9.8	S	
110	205	0 40.4	+41 41	And	17 × 10	8.0	E?	

: denotes approximate value.
Types: diffuse nebula (Di), globular cluster (Gb), open cluster (OC), planetary nebula (Pl), or galaxy (E for elliptical, Ir for irregular, S for spiral).
Magnitudes with a colon are approximate visual magnitudes.
(Adapted from *Sky Catalogue 2000.0*, Vol. 2, Sky Publishing Corp., 1985.)

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Following M. Golay (*Introduction to Astronomical Photometry*, D. Reidel Publishing Company, 1974), we can write the following expression for the apparent magnitude difference on the Earth of two stars:

$$m_1 - m_2 = -2.5 \log \frac{\int_{\lambda_a}^{\lambda_b} \alpha_1^2 I_1(\lambda)\, T_i(\lambda, d_1)\, T_a(\lambda, d_1)\, T_t(\lambda)\, T_f(\lambda) r(\lambda)\, \mathrm{d}\lambda}{\int_{\lambda_a}^{\lambda_b} \alpha_2^2 I_2(\lambda)\, T_i(\lambda, d_2)\, T_a(\lambda, d_2)\, T_t(\lambda)\, T_f(\lambda) r(\lambda)\, \mathrm{d}\lambda},$$

where

$I_1(\lambda)$ the spectral radiance of star 1.

$I_2(\lambda)$ the same for star 2.

α_1 and α_2 the apparent diameters of stars 1 and 2, which are assumed to be spherical and emit isotropic radiation.

$T_i(\lambda, d_1)$ the fraction of the radiation of star 1 transmitted by interstellar space in the direction d_1 of star 1.

$T_i(\lambda, d_2)$ the same for star 2.

$T_a(\lambda, d_1)$ the fraction of stellar radiation transmitted by the Earth's atmosphere when star 1 is in direction d_1.

$T_a(\lambda, d_2)$ the same for star 2 when it is in direction d_2.

$T_t(\lambda)$ the fraction of stellar radiation transmitted by the optical system of the telescope t, whose entry pupil is perpendicular to the star's direction.

$T_f(\lambda)$ the fraction of stellar radiation transmitted by a filter f placed in front of the receiver.

$r(\lambda)$ the response of the receiver r which, for simplicity, is assumed to depend only upon λ.

The limits of integration, λ_a and λ_b where $\lambda_b > \lambda_a$ are defined by

$$\lambda \geqslant \lambda_b \quad T_a \cdot T_t \cdot T_f \cdot r \equiv 0,$$

$$\lambda \leqslant \lambda_a \quad T_a \cdot T_t \cdot T_f \cdot r \equiv 0.$$

Let

$$S(\lambda) = T_t(\lambda)\, T_f(\lambda) r(\lambda),$$

the response of the photometric system and

$$E(\lambda) = \frac{\alpha^2}{4} I(\lambda)\, T_i(\lambda, d),$$

the stellar spectral irradiance at the top of the Earth's atmosphere, then the difference in apparent magnitudes for two stars outside the Earth's atmosphere is given by the expression:

$$(m_1 - m_2)_0 = -2.5 \log \frac{\int_{\lambda_a}^{\lambda_b} E_1(\lambda) \cdot S(\lambda)\, \mathrm{d}\lambda}{\int_{\lambda_a}^{\lambda_b} E_2(\lambda) \cdot S(\lambda)\, \mathrm{d}\lambda}.$$

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We can define three wavelengths for a photometric system:

(1) $$\lambda_0 = \frac{\int_{\lambda_a}^{\lambda_b} \lambda S(\lambda)\,\mathrm{d}\lambda}{\int_{\lambda_a}^{\lambda_b} S(\lambda)\,\mathrm{d}\lambda},$$

the mean wavelength of the pass-band defined by the response function $S(\lambda)$.

(2) $$E(\lambda_i)\int_{\lambda_a}^{\lambda_b} S(\lambda)\,\mathrm{d}\lambda = \int_{\lambda_a}^{\lambda_b} E(\lambda)S(\lambda)\,\mathrm{d}\lambda,$$

where λ_i is the isophotal wavelength.

(3) $$\lambda_{\mathrm{eff}} = \frac{\int_{\lambda_a}^{\lambda_b} \lambda E(\lambda)S(\lambda)\mathrm{d}\lambda}{\int_{\lambda_a}^{\lambda_b} E(\lambda)S(\lambda)\mathrm{d}\lambda},$$

the effective wavelength.

$$\lambda_{\mathrm{eff}} - \lambda_0 = \frac{E'(\lambda_0)}{E(\lambda_0)}\cdot\mu^2 \quad \text{and} \quad \lambda_i - \lambda_0 = \tfrac{1}{2}\mu^2\frac{E''(\lambda_0)}{E'(\lambda_0)},$$

where

$$\mu^2 = \frac{\int (\lambda - \lambda_0)^2 S(\lambda)\,\mathrm{d}\lambda}{\int S(\lambda)\,\mathrm{d}\lambda},$$

The color index of a star is defined by

$$C_{AB} \equiv m_A - m_B = -2.5\log\frac{\int_A E(\lambda)S_A(\lambda)\,\mathrm{d}\lambda}{\int_B E(\lambda)S_B(\lambda)\,\mathrm{d}\lambda} + \text{constant},$$

where A and B represent two different spectral bands.

The relationships between heterochromatic magnitude m_{λ_0} (obtained with a band of mean wavelength λ_0) and monochromatic magnitudes taken at the isophotal wavelength, $m(\lambda_i)$, at the mean wavelength $m(\lambda_0)$ and at the effective wavelength $m(\lambda_{\mathrm{eff}})$:

$$m_{\lambda_0} = m(\lambda_i) + S, \quad \text{where } S = -2.5\log\int_{\lambda_a}^{\lambda_b} S(\lambda)\,\mathrm{d}\lambda.$$

$$m(\lambda_i) - m(\lambda_0) = -0.543\mu^2\left(\frac{E''(\lambda_0)}{E(\lambda_i)}\right).$$

$$m(\lambda_i) - m(\lambda_{\mathrm{eff}}) = -0.543\left(\frac{\lambda_{\mathrm{eff}}E'(\lambda_{\mathrm{eff}})}{E(\lambda_{\mathrm{eff}})} + 1\right)\frac{\lambda_0 - \lambda_{\mathrm{eff}}}{\lambda_{\mathrm{eff}}}$$

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Standard photometric systems

Standard U, B, V, R, I and long wavelength systems

Filter band	λ_0[a] (μm)	$\Delta\lambda_0$ (FWHM) (μm)	Absolute spectral irradiance for mag = 0.0 $f_\lambda(0)$ (erg cm^{-2} s^{-1} Å^{-1})	$f_\nu(0)$ (W m^{-2} Hz^{-1})
U	0.365	0.068	4.27×10^{-9}	1.90×10^{-23}
B	0.44	0.098	6.61×10^{-9}	$4.27(4.64)^{[b]} \times 10^{-23}$
V	0.55	0.089	3.64×10^{-9}	3.67×10^{-23}
R	0.70	0.22	1.74×10^{-9}	2.84×10^{-23}
I	0.90	0.24	8.32×10^{-10}	2.25×10^{-23}
J	1.25	0.3	3.18×10^{-10}	1.65×10^{-23}
H	1.65	0.4	1.18×10^{-10}	1.07×10^{-23}
K	2.2	0.6	4.17×10^{-11}	6.73×10^{-24}
L	3.6	1.2	6.23×10^{-12}	2.69×10^{-24}
M	4.8	0.8	2.07×10^{-12}	1.58×10^{-24}
N	10.2		1.23×10^{-13}	4.26×10^{-25}

[a] $\lambda_0 = \int \lambda S(\lambda)\,d\lambda / \int S(\lambda)\,d\lambda$, where $S(\lambda)$ is the photometer response function.
[b] From S. Kleinmann.
U, B, R, I, N values from Allen, C. W., *Astrophysical Quantities*. The Athlone Press (1973). *V, J, H, K, L, M* values from Wamsteker, W., *Astron. Astrophys.*, **97**, 329 (1981).

The spectral irradiance for a star of a given magnitude is given either by:

$$\log f_\lambda(m_x) = -0.4m_x + \log f_\lambda(0),$$

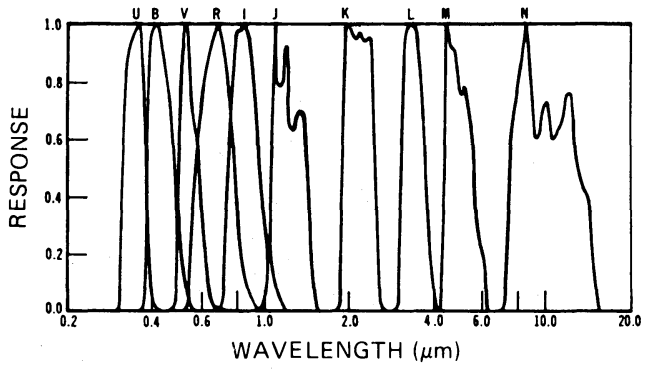
where $f_\lambda(m_x)$ is the spectral irradiance in erg cm^{-2} s^{-1} Å^{-1} of a star of magnitude (m_x) in the x filter band at the mean wavelength $\lambda_0(x)$, or

$$\log f_\nu(m_x) = -0.4m_x + \log f_\nu(0),$$

where $f_\nu(m_x)$ is the spectral irradiance in W m^{-2} Hz^{-1}.

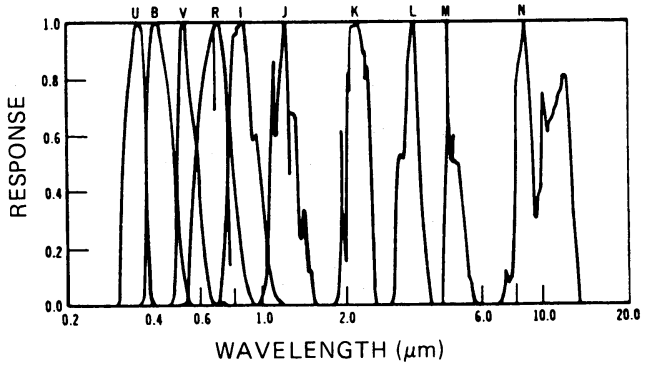
The relationships above are for the irradiance at the top of the Earth's atmosphere and are valid for *B* through *M* stars.

Photometer response curves for UBVRI and long wavelength systems. (Adapted from Webbink, R. F. & Jeffers, W. Q., *Space Sci. Rev.*, **10**, 191 1969.)



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Response curves of photometer plus atmosphere. (Adapted from Webbink, R. F. & Jeffers, W. Q., *Space Sci. Rev.*, **10**, 191, 1969.)



List of UBV primary standard stars

HD No.	Name	V	$B-V$	$U-B$	Spectral type
12 929	α Ari	2.00	+1.151	+1.12	K2 III
18 331	HR 875	5.17	+0.084	+0.05	A1 V
69 267	β Cnc	3.52	+1.480	+1.78	K4 III
74 280	η Hya	4.30	−0.195	−0.74	B3 V
135 742	β Lib	2.61	−0.108	−0.37	B8 V
140 573	α Ser	2.65	+1.168	+1.24	K2 III
143 107	ε CrB	4.15	+1.230	+1.28	K3 III
147 394	τ Her	3.89	−0.152	−0.56	B5 IV
214 680	10 Lac	4.88	−0.203	−1.04	O9 V
219 134	HR 8832	5.57	+1.010	+0.89	K3 V

(List taken from Strand, K. A. A., ed., *Basic Astronomical Data*, University of Chicago Press, Chicago, 1963.)

Standard stars for the JHKLM system

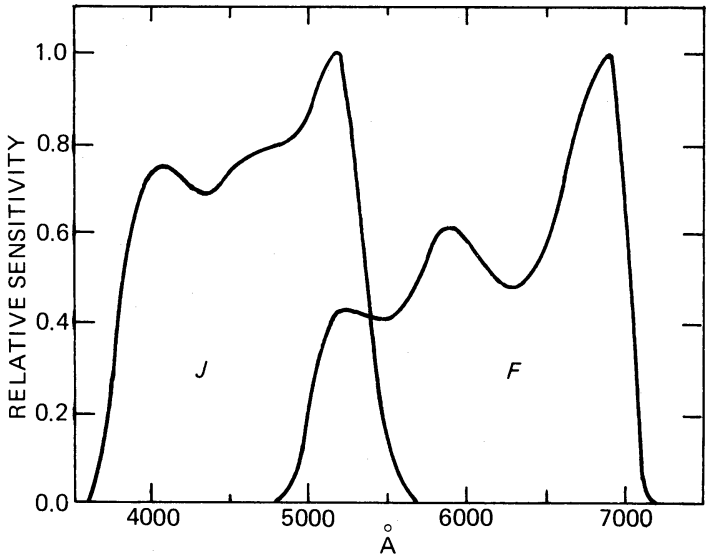
Standard	BS	Spectral type	m_{vis}	J	H	K	L	M
0	519	gM 4	5.49	2.117	1.317	1.078	0.890	1.181
1	721	B5 III	4.25	4.548	4.575	4.604	4.601	4.689
2	1195	G5 III	4.17	2.672	2.233	2.119	2.025	2.156
3	2827	B5 Ia	2.44	2.565	2.548	2.557	2.472	2.542
4	4216	G5 III	2.69	1.148	0.744	0.622	0.530	0.673
5	5530	F5 IV	5.16	4.408	4.194	4.156	4.092	4.134
6	7120	K3 III	4.98	2.822	2.197	2.052	1.910	2.103
7	8204	G4 Ibp	3.74	2.346	1.964	1.865	1.794	1.882
8	8502	K3 III	2.85	0.558	−0.077	−0.091	−0.372	−0.199
9	8728	A3 V	1.16	1.075	1.034	1.019	0.998	1.025

(List taken from Wamstecker, W., *Astron. Astrophys.*, **97**, 329, 1981.)

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Kron photographic J and F bands

Sensitivity functions $S_\lambda(\lambda)$ for the J waveband (*left*) and the F waveband (*right*). (From Kron, R. G., *Ap. J.*, **43**, 305, 1980.)



The earlier photovisual (m_{pv}) and photographic (m_{pg}) magnitudes are related to the standard B and V magnitudes by:

$$B \equiv m_B = m_{pg} + 0.11,$$

$$V \equiv m_V = m_{pv} + 0.00.$$

Color index,

$$C = m_{pg} - m_V = B - V - 0.11.$$

Bolometric correction,

$$BC = m_b - m_V = M_b - M_V,$$

where m_b (M_b) is the apparent (absolute) bolometric magnitude, a measure of the total energy output of a star.

$$M_b^{star} - 4.72 = -2.5 \log(L_{star}/L_\odot),$$

where L_{star} and $L_\odot = 3.83 \times 10^{33}$ erg s^{-1} are the absolute luminosities of the star and the Sun, respectively.

$$L_{star} = 2.97 \times 10^{35} \times 10^{-0.4 M_b} \quad \text{erg s}^{-1}.$$

The total irradiance at the top of the Earth's atmosphere is

$$f = 2.48 \times 10^{-5} \times 10^{-0.4 m_b} \quad \text{erg cm}^{-2}\,\text{s}^{-1}$$

for a star of apparent bolometric magnitude m_b.

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Assuming black-body radiation, the spectral photon irradiance from a star of apparent bolometric magnitude m_b is given by:

$$f(\lambda) = \frac{8.48 \times 10^{34} \times 10^{-0.4 m_b}}{T_e^4 \lambda^4 [\exp(1.44 \times 10^8 / \lambda T_e) - 1]} \quad \text{photons cm}^{-2}\,\text{s}^{-1}\,\text{Å}^{-1}$$

λ in Å; T_e the effective temperature of the star in K (e.g., A0 star; $m_V = 0$, $T_e = 10800, BC = -0.40, \lambda = 5000$ Å; $f(\lambda) = 10^3$ photons $\text{cm}^{-2}\,\text{s}^{-1}\,\text{Å}^{-1}$).

Interstellar reddening

The observed color index is given by

$$C_{ij} = C_{ij}^0 + [A(\lambda_i) - A(\lambda_j)] \equiv C_{ij}^0 + E_{ij},$$

where

$A(\lambda)$ = amount of interstellar absorption at λ,
C_{ij}^0 = intrinsic color index of the star,
$E_{ij} \equiv$ color excess.

In the UBV system, the color excesses are

$$E(B-V) \equiv (B-V) - (B-V)_0,$$

$$E(U-B) \equiv (U-B) - (U-B)_0$$

(subscript zero denotes intrinsic values).

$$A_V / E(B-V) = 3.2 \pm 0.2 \quad \text{(normal regions)}$$

$$\frac{E(U-B)}{E(B-V)} = 0.72 + 0.05 E(B-V).$$

Relationship of reddening $E(B-V)$ to the hydrogen column density:

$$\langle N(\text{HI} + H_2)/E(B-V) \rangle = 5.8 \times 10^{21} \quad \text{atoms cm}^{-2}\,\text{mag}^{-1},$$

$$\langle N(\text{HI})/E(B-V) \rangle = 4.8 \times 10^{21} \quad \text{atoms cm}^{-2}\,\text{mag}^{-1}$$

(Bohlin *et al.*, *Ap. J.*, **224**, 132, 1978).

Visual extinction to the galactic center:

$$A_V \approx 30 \quad \text{mag}$$

(Becklin *et al.*, *Ap. J.*, **151**, 145, 1968).

The mean color excess $\bar{E}_{B-V}(b)$ at galactic latitude b for objects outside the absorbing layer can be estimated by:

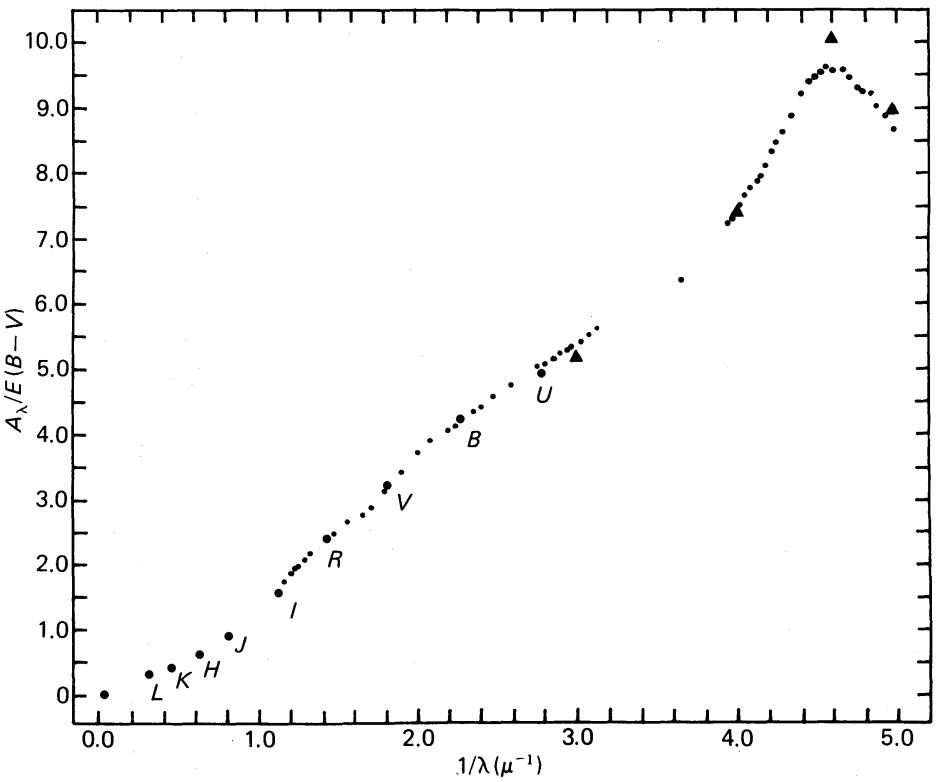
$$\bar{E}_{B-V}(b) = 0.06 \,\text{cosec}|b| - 0.06$$

(Woltjer, L., *Astron. Astrophys.*, **42**, 109, 1975).

A more general expression giving an estimate of interstellar absorption can be found in de Vaucouleurs *et al.*, *Second Reference Catalogue of Bright Galaxies*, University of Texas Press, 1976.

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λ (Å)	$1/\lambda$ (μ^{-1})	$A_\lambda/E(B-V)$	λ (Å)	$1/\lambda$ (μ^{-1})	$A_\lambda/E(B-V)$
3200	3.13	5.58	5556	1.80	3.12
3250	3.08	5.47	5840	1.71	2.91
3300	3.03	5.38	6050	1.65	2.80
3350	2.98	5.32	6436	1.55	2.65
3400	2.94	5.26	6790	1.47	2.48
3448	2.90	5.18	7100	1.41	2.35
3509	2.85	5.10	7550	1.32	2.18
3571	2.80	5.06	7780	1.28	2.06
3636	2.75	4.99	8090	1.24	1.98
3862	2.59	4.72	8188	1.22	1.94
4036	2.48	4.56	8370	1.20	1.88
4167	2.40	4.39	8446	1.18	1.85
4255	2.35	4.33	8710	1.15	1.72
4464	2.24	4.12	9700	1.03	1.50
4566	2.19	4.04	9832	1.02	1.48
4780	2.09	3.91	10 256	0.95	1.36
5000	2.00	3.70	10 610	0.94	1.28
5263	1.90	3.41	10 796	0.93	1.26
5480	1.82	3.20	10 870	0.92	1.22



(Courtesy of R. Schild, Center for Astrophysics.)

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Absolute magnitude

The absolute magnitude M of a star is the apparent magnitude it would have if placed at a distance of 10 parsecs:

$$m - M = 5 \log D - 5 + A,$$

where D is the distance to the star in parsecs and A is a correction for interstellar absorption expressed in magnitude units. $m - M \equiv$ distance modulus. Solving for D:

$$D = 10^{[1 + (m - M - A)/5]}.$$

Moon, night sky, sun, and planetary brightness

Moon

$V(R, \phi) = 0.23 + 5 \log R - 2.5 \log P(\phi)$,

$V(R, \phi) =$ the apparent V magnitude of the Moon,

$R =$ the observer–Moon distance in AU, and

$\phi =$ the phase angle = angle between the Sun and the Earth as seen from the Moon.

$P(0°) = 1.000$, $P(40°) = 0.377$, $P(80°) = 0.127$,

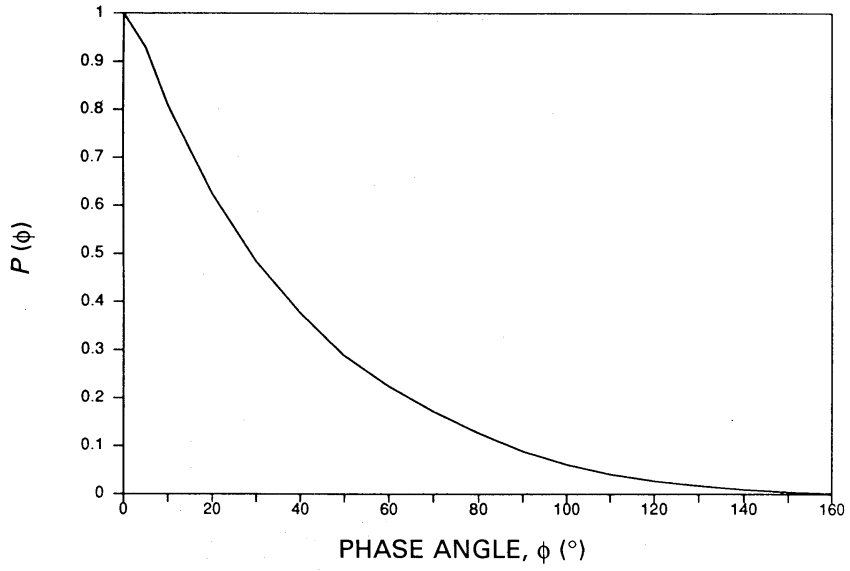
$P(120°) = 0.027$, $P(160°) = 0.001$.

Mean lunar distance $= 2.570 \times 10^{-3}$ AU.

The V magnitude of the Moon at the Earth at opposition (full moon) is -12.73.

(Adapted from Wertz, J. R., *Spacecraft Attitude Determination and Control*, D. Reidel, 1980)

The Moon's phase law.



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Night sky

Total brightness (zenith, mean sky) $\approx 1 \quad (m_V = 22.5)$ star arcsec^{-2}.

Sun

Apparent magnitude	*Color index*	*Absolute magnitude*
$U = -26.06$	$U - B = +0.10$	$M_U = +5.51$
$B = -26.16$	$B - V = +0.62$	$M_B = +5.41$
$V = -26.78$	$BC = -0.07$	$M_V = +4.79$
$m_b = -26.85$		$M_b = +4.72$

Planetary brightness

The change in the brightness of a planet because of the changing distance from the Sun (r) and the Earth (Δ) is given by:

$$V = V(1,0) + 5\log(r\Delta) + \alpha(p),$$

where

$V(1,0)$ = visual magnitude of planet reduced to a distance of 1 AU from both the Sun and the Earth and phase angle $p = 0$,

α = phase law; change of planet brightness with p,

p = phase angle; angle between Sun and Earth seen from the planet

$$\cos p = \frac{r^2 + \Delta^2 - R^2}{2r\Delta},$$

where R = distance from the Earth to the Sun.

Planet	$V(1,0)$[a]	α[b]
Mercury	-0.42 mag	$+0.027p + 2.2 \times 10^{-13}p^6$
Venus	-4.40	$+0.013p + 4.2 \times 10^{-7}p^3$
Mars	-1.52	$+0.016p$
Jupiter	-9.40	$+0.014p$
Saturn	-8.88	$+0.044L - 2.6\sin B + 1.2\sin^2 B$
Uranus	-7.19	$+0.001p$
Neptune	-6.87	$+0.001p$
Pluto	-1.0	

p in degrees; L = Saturnicentric ring longitude difference of Sun and Earth; B = Saturnicentric ring latitude of Earth; $0° < L < 6°$, $0° < |B| < 27°$.

[a] (from the *The Nautical Almanac*)

[b] (from Allen, C. W., *Astrophysical Quantities*)

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Time

The *Julian date* (*JD*) corresponding to any instant is the interval in *mean solar days* since 4713 BC January 1 at Greenwich mean noon (1200 UT). (Midnight, January 1, 1961 = 0000 UT January 1, 1961 = JD 2,437,300.5.)

A procedure (from Fliegel, H. F. & van Flandern, T. C., *Comm. ACM*, **11**, 657, 1968) for finding the Julian date (*JD*) for a given year (*I*), month (*J*), and day of the month (*K*) is given by the following FORTRAN (integer) arithmetic statement:

$$JD = K - 32075 + 1461*(I + 4800 + (J - 14)/12)/4 + 367*(J - 2 - (J - 14)/12*12)/12 - 3*((I + 4900 + (J - 14)/12)/100)/4.$$

For example, December 25, 1981 ($I = 1981$, $J = 12$, $K = 25$) = *JD* 2,444,964.

One *Besselian year* is the period of a complete circuit of the mean Sun in right ascension beginning at the instant when its right ascension is $18^h\,40^m$. The epochs to which stellar coordinates are referred are in Besselian year numbers. (The epoch 1950.0 started December 31, 1949 at 2209 UT.)

A *mean sidereal day* is the interval between two successive upper culminations or transits of the vernal equinox.

The *civil* or *mean solar day* is $\frac{1}{365.2422}$ of a *tropical year*, the interval between two successive passages of the Sun through the vernal equinox.

Sidereal time is the hour angle of the vernal equinox.

Apparent solar time is the local hour angle of the Sun, expressed in hours, plus 12 hours.

Mean solar time is the local hour angle, plus 12 hours, of a fictitious *mean sun* which moves along the equator at a constant rate equal to the average annual rate of the Sun.

Mean solar time at 0° longitude is called *universal time* (*UT*, formerly *Greenwich mean time* or GMT).

Ephemeris time (*ET*) is based on the time interval of a *tropical year*. 1 *ephemeris second is* $\frac{1}{31\,556\,925.9747}$ of the tropical year 1900.

$$ET = UT + \Delta T \quad (\Delta T = +52.5\text{ s, January 1, 1982}).$$

International atomic time $= ET - 32.18\ s$.

In 1981:

1 mean solar day = 1.002 737 909 31 mean sidereal days
= $24^h\,03^m\,56^s.555\,36$ of mean sidereal time.

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Pacific standard time $= UT - 8^h$.
Mountain standard time $= UT - 7^h$.
Central standard time $= UT - 6^h$.
Eastern standard time $= UT - 5^h$.
Colonial standard time $= UT - 4^h$.
Western European time $= UT$.
Central European time $= UT + 1^h$.
Eastern European time $= UT + 2^h$.

Notation for time-scales

A summary of the notation for time-scales and related quantities used in the *Astronomical Almanac* is given below. Additional information is given in the *Supplement* to the *Almanac*.

UT = UT1; universal time; counted from 0^h at midnight; unit is mean solar day.
UT0 local approximation to universal time; not corrected for polar motion.
GMST Greenwich mean sidereal time; GHA of mean equinox of date.
GAST Greenwich apparent sidereal time; GHA of true equinox of date.
TAI international atomic time; unit is the SI second.
UTC coordinated universal time; differs from TAI by an integral number of seconds, and is the basis of most radio time signals and legal time systems.
ΔUT = UT − UTC; increment to be applied to UTC to give UT.
DUT = predicted value of ΔUT, rounded to $0^s.1$, given in some radio time signals.
ET ephemeris time; was used in dynamical theories and in the Almanac from 1960–83; but is now replaced by TDT and TDB.
TDT terrestrial dynamical time; used as time-scale of ephemerides for observations from the Earth's surface. TDT = TAI + $32^s.184$.
TDB barycentric dynamical time; used as time-scale of ephemerides referred to the barycenter of the solar system.
ΔT = ET − UT (prior to 1984); increment to be applied to UT to give ET.
ΔT = TDT − UT (1984 onwards); increment to be applied to UT to give TDT.
ΔT = TAI + $32^s.184$ − UT.
ΔAT = TAI − UTC; increment to be applied to UTC to give TAI.
ΔET = ET − UTC; increment to be applied to UTC to give ET.
ΔTT = TDT − UTC; increment to be applied to UTC to give TDT.

For most purposes, ET up to 1983 December 31 and TDT from 1984 January 1 can be regarded as a continuous time-scale. Values of ΔT for the years 1620 onwards are given in the *Astronomical Almanac*.

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The name Greenwich mean time (GMT) is not used in astronomy since it is ambiguous and is now used, in the sense of UTC in addition to the earlier sense of UT; prior to 1925 it was reckoned for astronomical purposes from Greenwich mean noon (12^h UT).

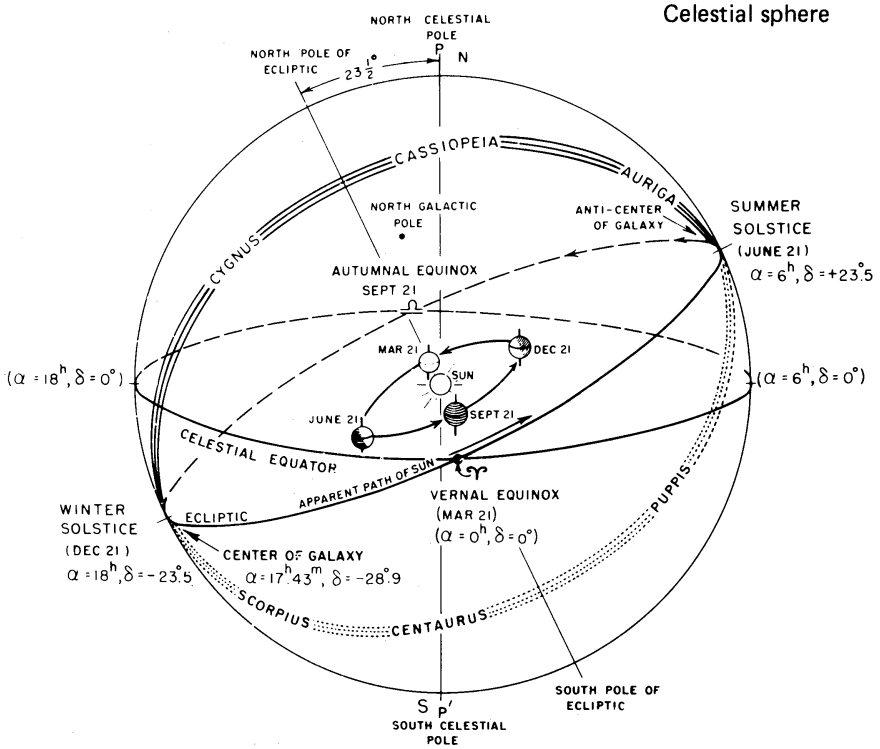
Relationships with local time and hour angle

The following general relationships are used:

Local mean solar time	= universal time + east longitude.
Local mean sidereal time	= Greenwich mean sidereal time + east longitude.
Local apparent sidereal time	= local mean sidereal time + equation of equinoxes = Greenwich apparent sidereal time + east longitude.
Local hour angle	= local apparent sidereal time − apparent right ascension = local mean sidereal time − (apparent right ascension − equation of equinoxes).

A further small correction for the effect of polar motion is required in the production of very precise observations.

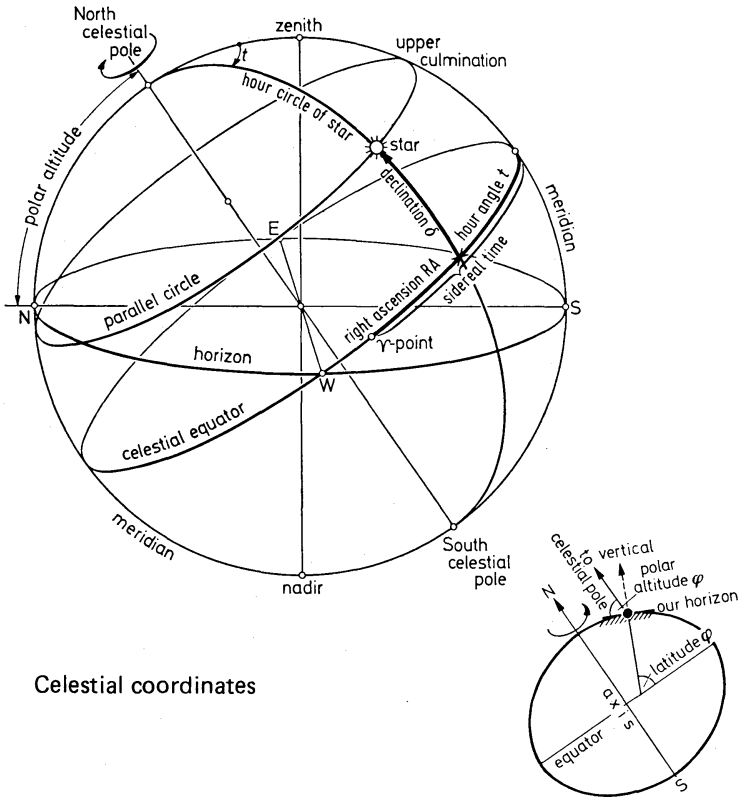
The celestial sphere



(Adapted from Valley, S. L., ed., *Handbook of Geophysics and Space Environment*, AFCRL, 1965.)

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Celestial coordinates

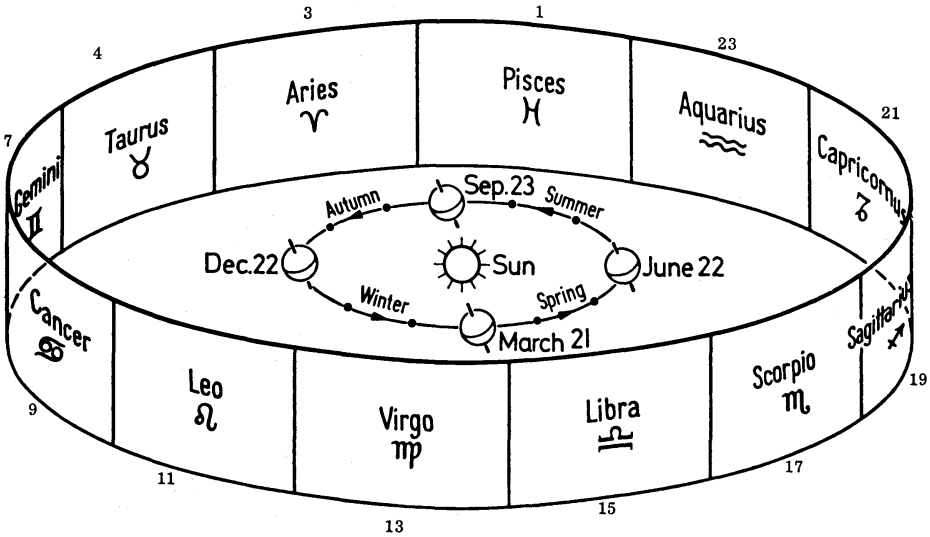


Celestial coordinates

(Unsoeld, A., *The New Cosmos*, Springer-Verlag, 1969, with permission.)

The Zodiac

Path of the Earth around the Sun, seasons, and Zodiac. Perihelion is 2 January and aphelion is 2 July. Right ascension in hours of each constellation is given. (Adapted from Unsoeld, A., *The New Cosmos*, Springer-Verlag, 1969.)



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Astronomical coordinate transformations

Horizon–equatorial (celestial) systems

$\cos a \sin A = +\cos\delta \sin h,$

$\cos a \cos A = -\sin\delta \cos\varphi + \cos\delta \cos h \sin\varphi,$

$\sin a = \sin\delta \sin\varphi + \cos\delta \cos h \cos\varphi,$

$\cos\delta \sin h = \cos a \sin A,$

$\cos\delta \cos h = \sin a \cos\varphi + \cos a \cos A \sin\varphi,$

$\sin\delta = \sin a \sin\varphi - \cos a \cos A \cos\varphi,$

h = local sidereal time $-\alpha$,

A = azimuth, toward West from South,

a = altitude,

φ = observer's latitude,

h = local hour angle,

α = right ascension,

δ = declination.

Ecliptic–equatorial (celestial) systems

$\cos\delta \cos\alpha = \cos\beta \cos\lambda,$

$\cos\delta \sin\alpha = \cos\beta \sin\lambda \cos\varepsilon - \sin\beta \sin\varepsilon,$

$\sin\delta = \cos\beta \sin\lambda \sin\varepsilon + \sin\beta \cos\varepsilon,$

$\cos\beta \cos\lambda = \cos\delta \cos\alpha,$

$\cos\beta \sin\lambda = \cos\delta \sin\alpha \cos\varepsilon + \sin\delta \sin\varepsilon,$

$\sin\beta = \sin\delta \cos\varepsilon - \cos\delta \sin\alpha \sin\varepsilon,$

α = right ascension, δ = declination,

λ = ecliptic longitude, β = ecliptic latitude,

ε = obliquity of the ecliptic $= 23°27'8\overset{''}{.}26 - 46\overset{''}{.}845T - 0\overset{''}{.}0059T^2 + 0\overset{''}{.}001\,81T^3$

where T is the time in centuries from 1900.

Galactic–equatorial (celestial) systems

$\cos b^{II} \cos(l^{II} - 33°) = \cos\delta \cos(\alpha - 282.25°),$

$\cos b^{II} \sin(l^{II} - 33°) = \cos\delta \sin(\alpha - 282.25°) \cos 62.6° + \sin\delta \sin 62.6°,$

$\sin b^{II} = \sin\delta \cos 62.6° - \cos\delta \sin(\alpha - 282.25°) \sin 62.6°,$

$\cos\delta \sin(\alpha - 282.25°) = \cos b^{II} \sin(l^{II} - 33°) \cos 62.6° - \sin b^{II} \sin 62.6°,$

$\sin\delta = \cos b^{II} \sin(l^{II} - 33°) \sin 62.6° + \sin b^{II} \cos 62.6°,$

l^{II} = new galactic longitude,

b^{II} = new galactic latitude,

α = right descension (1950.0),

δ = declination (1950.0),

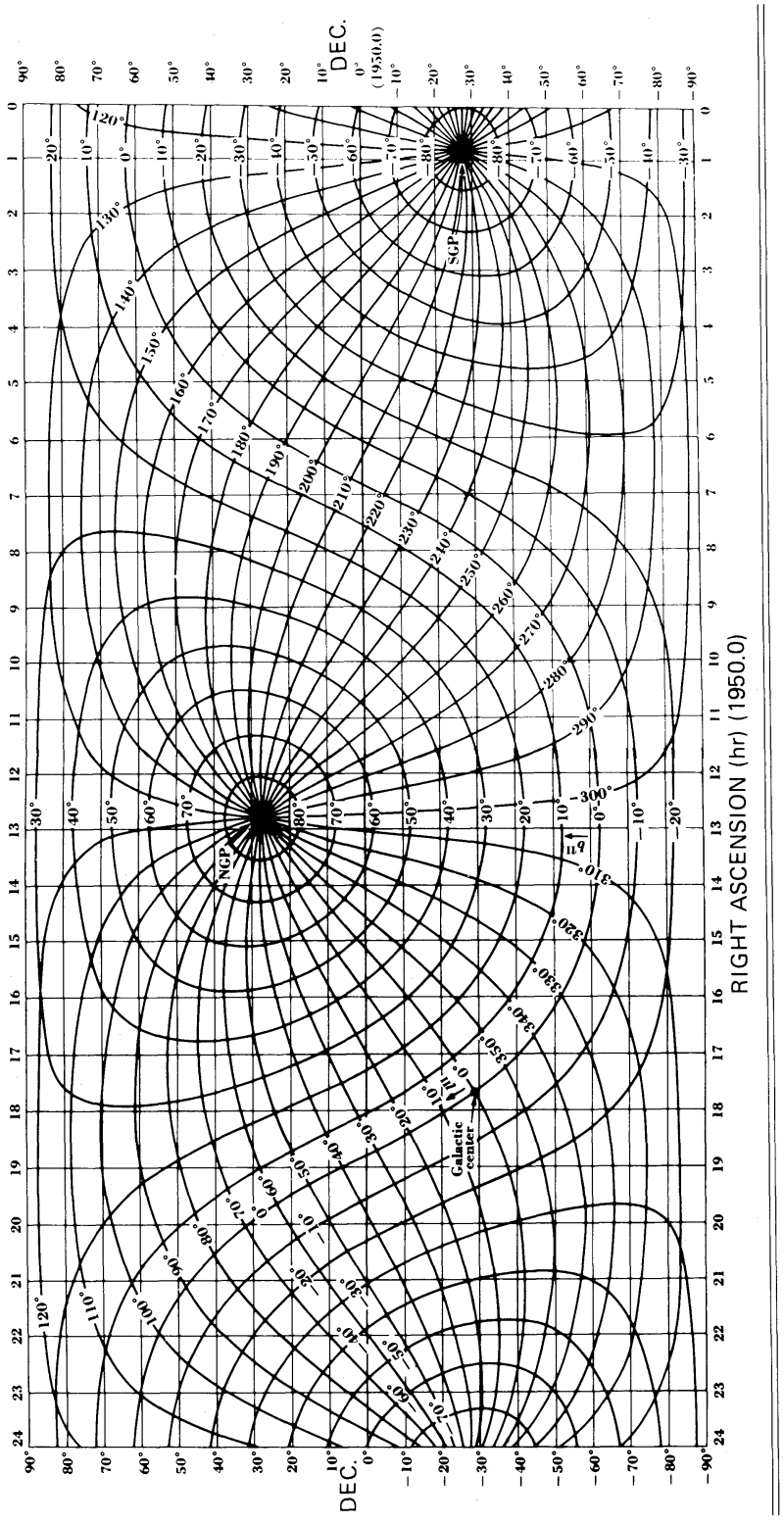
For, $l^{II} = b^{II} = 0$: $\alpha = 17^h42\overset{m}{.}4$, $\delta = -28°\,55'$ (1950.0);

$b^{II} = +90.0$, galactic north pole: $\alpha = 12^h\,49^m$, $\delta = +27\overset{\circ}{.}4$ (1950.0).

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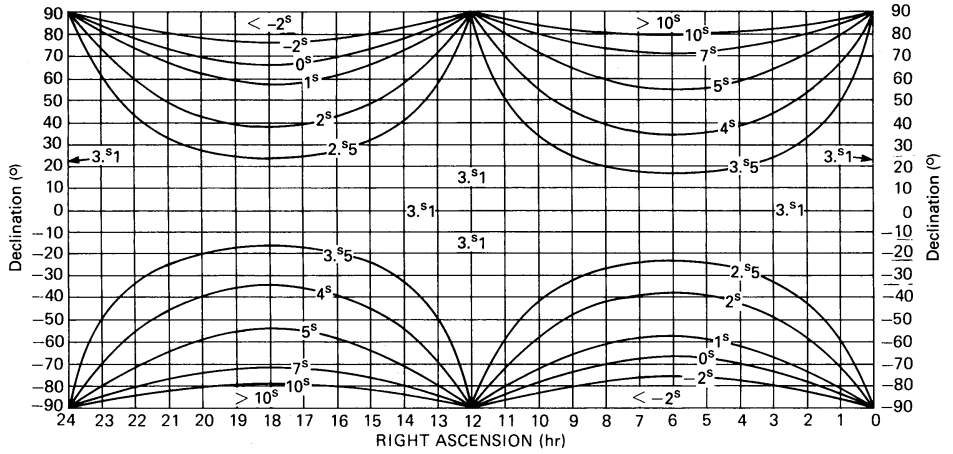
Galactic–equatorial (celestial) systems (cont.)

Chart for conversion of equatorial (1950.0) coordinates into new galactic coordinates ($l^{II}b^{II}$) or vice versa. (Kraus, J. D., *Radio Astronomy*, 2nd edn., with permission.)

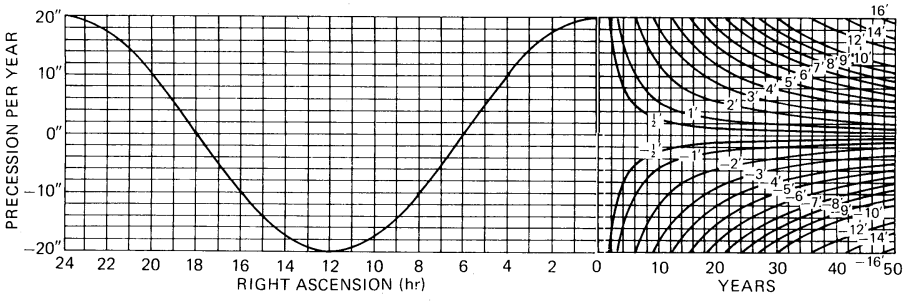


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Right-ascension precession in seconds of time per year.



Declination precession in seconds of arc per year (*left*) and minutes of arc as a function of interval in years (*right*).



Precession charts: The charts show the precession in right ascension in seconds of time per year and of declination in seconds of arc per year as a function of position as given by the relations

$$\Delta\alpha = 3^{s}.07 + 1^{s}.34 \sin\alpha \tan\delta \quad \text{per year},$$

$$\Delta\delta = 20'' \cos\alpha \quad \text{per year}.$$

The lower chart also indicates the precession in declination in minutes of arc as a function of the interval in years. For example, to find the precession for an object at RA = $04^{h}00^{m}$ for an 18-year interval one enters the chart at 4 hr, finding a precession of 10 sec of arc per year. Then moving horizontally to the right-hand chart to a point above 18 years the precession is found to be 3 min of arc for the 18-year interval.

The charts are useful for approximate precession determinations for intervals between epochs 1800.0 to 2000.0. (Kraus, J. D., *Radio Astronomy*, 2nd edn., with permission.)

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Major ground-based astronomical facilities

REFLECTING TELESCOPES

Clear aperture		Focal length	Prime focal ratio	In oper.	Latitude	Longitude	Elevation	Facility
600 cm	236 in	24.0 m	4.0	1976	43° 39′ N	41° 26′ E	2070 m	Bol'shoi Teleskop Azimutal'nyi Special Astrophysical Observatory Mount Pastukhov, USSR
508	200	16.8	3.3	1948	33° 21′ N	116° 52′ W	1706	George Ellery Hale Telescope Palomar Observatory Palomar Mountain, California
6×180	6×70	4.9	2.7	1979	31° 41′ N	110° 53′ W	2600	Multiple Mirror Telescope Mount Hopkins Observatory Mount Hopkins, Arizona
400	158	11.2	2.8	1976	30° 10′ S	70° 48′ W	2399	Cerro-Tololo Inter-American Observatory Cerro Tololo, Chile
389	153	12.7	3.3	1975	31° 17′ S	149° 04′ E	1164	Anglo-Australian Telescope Anglo-Australian Observatory Siding Spring Mountain, Australia
381	150	10.7	2.8	1973	31° 58′ N	111° 36′ W	2064	Nicholas U. Mayall Reflector Kitt Peak National Observatory Kitt Peak, Arizona
380	150	9.5	2.5	1979	19° 50′ N	155° 28′ W	4194	United Kingdom Infrared Telescope Royal Observatory, Edinburgh Mauna Kea, Hawaii
360	142	13.5	3.8	1979	19° 49′ N	155° 28′ W	4200	Canada–France–Hawaii Telescope Mauna Kea, Hawaii

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357	141	10.9	3.0	1976	29° 15′ S	70° 44′ W	2400	ESO 3.6-meter Telescope European Southern Observatory Cerro La Silla, Chile
350	138	12.2, 13.8	3.5, 4.0	1983	37° 14′ N	02° 32′ W	2168	Max Planck Institute for Astronomy German-Spanish Astronomical Center Calar Alto, Spain
305	120	15.2	5.0	1959	37° 20′ N	121° 39′ W	1277	C. Donald Shane Telescope Lick Observatory Mount Hamilton, California

SCHMIDT TELESCOPES

Clear aperture		Mirror diameter	Focal length	Focal ratio	In oper.	Latitude	Longitude	Elevation	Facility
134 cm	53 in	200 cm	4.0 m	3.0	1960	50° 59′ N	11° 43′ E	331 m	2-meter Telescope of the Karl Schwarzschild Observatorium near Tautenberg, East Germany
126	49.5	183	3.1	2.4	1948	33° 21′ N	116° 52′ W	1706	Palomar Schmidt Telescope Palomar Observatory Palomar Mountain, California
124	49	183	3.1	2.5	1973	31° 16′ S	149° 04′ E	1131	United Kingdom Schmidt Telescope Royal Observatory, Edinburgh Siding Spring Mountain, Australia
105	41	150	3.3	3.1	1976	35° 48′ N	137° 38′ E	1130	Kiso Station of the Tokyo Astronomical Observatory Kiso, Japan
100	39	162	3.0	3.1	1972	29° 15′ S	70° 44′ W	2400	ESO 1-meter Schmidt Telescope European Southern Observatory Cerro La Silla, Chile

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Major ground-based astronomical facilities (*cont.*)

SCHMIDT TELESCOPES

Clear aperture		Mirror diameter	Focal length	Focal ratio	In oper.	Latitude	Longitude	Elevation	Facility
100 cm	39 in	152 cm	3.0 m	3.0	1978	8° 47′ N	70° 52′ W	3600 m	Centro de Investigación de Astronomía 'F. J. Duarte' Llano del Hato, Venezuela
100	39	135	3.0	3.0	1963	59° 30′ N	17° 36′ E	33	Kvistaberg Schmidt Telescope Uppsala University Observatory Kvistaberg, Sweden
100	39	132	2.1	2.1	1961	40° 20′ N	44° 30′ E	1450	3TA-10 Schmidt Telescope Byurakan Astrophysical Observatory Mount Aragatz, Armenian SSR
90	35	152	3.2	3.5	1981	43° 45′ N	6° 56′ E	1270	Télescope de Schmidt Observatoire de Calern Calern, France
84	33	120	2.1	2.5	1958	50° 48′ N	4° 21′ E	105	Télescope Combiné de Schmidt Observatoire Royal de Belgique Uccle, Bruxelles, Belgium

REFRACTING TELESCOPES

Clear aperture		Focal length	Prime ratio	In oper.	Latitude	Longitude	Elevation	Facility
101 cm	40 in	19.4 m	19.2	1897	42° 34′ N	88° 33′ W	334 m	Yerkes Observatory University of Chicago Williams Bay, Wisconsin

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89.5	36	17.6	19.7	1888	37° 20′ N	121° 39′ W	1284	36-inch Refractor Lick Observatory Mount Hamilton, California
83	33	16.2	19.5	1889	48° 48′ N	2° 14′ E	162	Observatoire de Paris Meudon, France
80	31	12.0	15.0	1899	52° 23′ N	13° 04′ E	107	Zentralinstitut für Astrophysik Telegrafenberg, Potsdam, E. Germany
76	30	14.1	18.6	1914	40° 29′ N	80° 01′ W	370	The Thaw Refractor Allegheny Observatory River View Park, Pittsburgh, PA
74	29	17.9	24.2	1886	43° 43′ N	7° 18′ E	376	Lunette Bischoffsheim Observatoire de Nice Mont Gros, France
71	28	8.5	11.9	1894	51° 29′ N	0° 00′	47	28-inch Visual Refractor Old Royal Greenwich Observatory Greenwich, England
68	27	21.0	30.9	1896	52° 29′ N	13° 29′ E	41	Grosser Refraktor Archenhold-Sternwarte Alt Treptow, Berlin, E. Germany
67	26	10.5	15.7	1880	48° 14′ N	16° 20′ E	240	Grosser Refraktor Institut für Astronomie Vienna, Austria
67	26	10.9	16.3	1925	26° 11′ S	28° 04′ E	1806	The Innes Telescope Outstation/South African Astronomy Observatory Johannesburg, South Africa
67	26.3	9.9	14.9	1883	38° 02′ N	78° 31′ W	259	Leander McCormick Observatory Mount Jefferson Charlottesville, Virginia

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Major ground-based astronomical facilities (*cont.*)

REFRACTING TELESCOPES

Clear aperture		Focal length	Prime ratio	In oper.	Latitude	Longitude	Elevation	Facility
66 cm	26 in	9.9 m	15.0	1873	38° 55′ N	77° 04′ W	92 m	26-inch Equatorial United States Naval Observatory Washington, DC
66	26	6.9	10.4	1899	50° 52′ N	0° 20′ E	34	The Thompson Refractor Royal Greenwich Observatory Herstmonceux Castle, Hailsham, UK
66	26	10.8	16.4	1925	35° 19′ S	149° 00′ E	769	Yale–Columbia Refractor Mt. Stromlo and Siding Springs Observatory, Mt. Stromlo, ACT, Australia

RADIO TELESCOPES/ANTENNAE

Aperture	Frequency range (MHz)	Latitude	Longitude	Elevation	Facility
305 m dish (non-steerable)	50–3000	18° 21′ N	66° 45′ W	365 m	Arecibo Observatory Arecibo, Puerto Rico
100 m dish (steerable)	600–15 000	50° 32′ N	6° 53′ E	366	MPI für Radioastronomie Effelsberg, Federal Republic of Germany
14 25 m dishes (syn. tel.)	610, 1415, 4995	52° 55′ N	6° 36′ E	5	Westerbork Radio Observatory Hooghalen, The Netherlands
64 m dish (steerable)	500–5000	33° 00′ S	148° 16′ E	392	Australian National Radio Astronomy Observatory, Parkes, New South Wales, Australia

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Rectangular arrays	1415	33° 52′ S	150° 46′ E		Radio Astronomy Observatory Fleurs, New South Wales, Australia
Radioheliograph	80, 160, 327	30° 19′ S	150° 46′ E	215	CSIRO Solar Radio Observatory Culgoora, New South Wales, Australia
76 m dish (steerable)	0.3–4000	53° 14′ N	2° 18′ W	78	Nuffield Radio Astronomy Laboratories Jodrell Bank, Macclesfield Cheshire, England
8 element interferometer (5 km baseline)	2695, 5000, 15 375	52° 10′ N	0° 03′ E	17	Mullard Radio Astronomy Observatory Cambridge, England
40 m dish (steerable)	500–12 000 18 000–24 000	37° 14′ N	118° 17′ W	1216	Owens Valley Radio Observatory Big Pine, California
91.4 m dish (steerable)†	0.3–5000	38° 26′ N	79° 50′ W	825	National Radio Astronomy Observatory Greenbank, West Virginia
45.7 m dish (steerable)	400–10 000	45° 57′ N	78° 04′ W	260	Algonquin Radio Observatory Lake Traverse, Ontario, Canada
V(ery) L(arge) A(rray) 27 25 m dishes (steerable)	1420, 1700, 5000, 15 000, 24 010	34° 05′ N	107° 37′ W	2124	National Radio Astronomy Observatory Plains of San Augustin, New Mexico
30 m dish	$\lambda_{min} = 1.4$ mm	37° 02′ N	03° 12′ W	2950	Institut de Radio Astronomie Millimétrique Lomo de Dilar, Granada, Spain
45 m dish	$\lambda_{min} = 3$ mm	36° N	138° E	1400	Science Research Council Nagano, Japan

(Adapted from Classen, J. & Sperling, N., *Sky and Telescope*, **61**, 303, 1981.)
† Note added in proof: Structure collapsed on November 15, 1988.

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The Hubble Space Telescope
(Material for this section was taken from STScI document SC-02, 'Call for proposals', October, 1985.)

The Hubble Space Telescope (HST) is managed by the Space Telescope Science Institute (STScI):

Space Telescope Science Institute
3700 San Martin Drive
Baltimore, MD 21218
USA

Tel.: (301) 338-4700

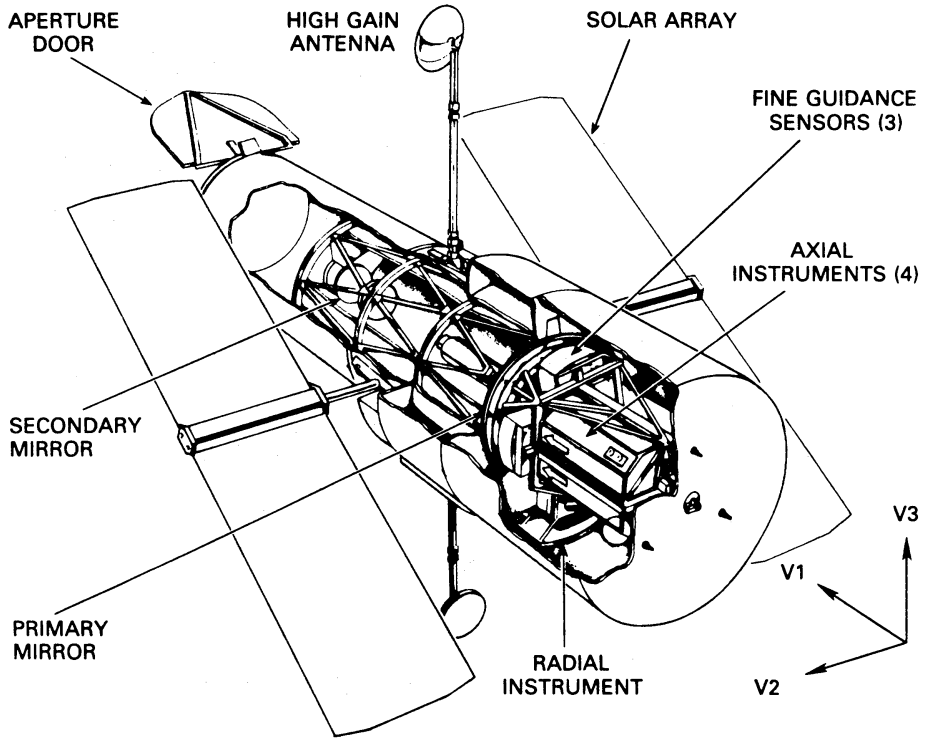
To allow European astronomers to make use of the Hubble Space Telescope, the European Space Agency (ESA) has established the Space Telescope–European Coordinating Facility (ECF). The address of the ST-ECF:

Space Telescope–European Coordinating Facility
European Southern Observatory
Karl-Schwarzschild-Str. 2
D-8046 Garching bei München
Federal Republic of Germany

Tel.: (89) 32-006-291
Telex: 05-28282-22 EO D
Telefax: +49-89-3202362

An overview of the HST dealing with the performance of the telescope and instruments and plans for observations and data reduction and analysis can be found in the NASA publication, *The Space Telescope Observatory*, special session of commission 44, IAU 18th General Assembly, 1982, NASA CP-2244.

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HST nominal orbital parameters

Altitude	500 km
Inclination	28°.5
Orbital period	95 min
Orbital precession period	54 days

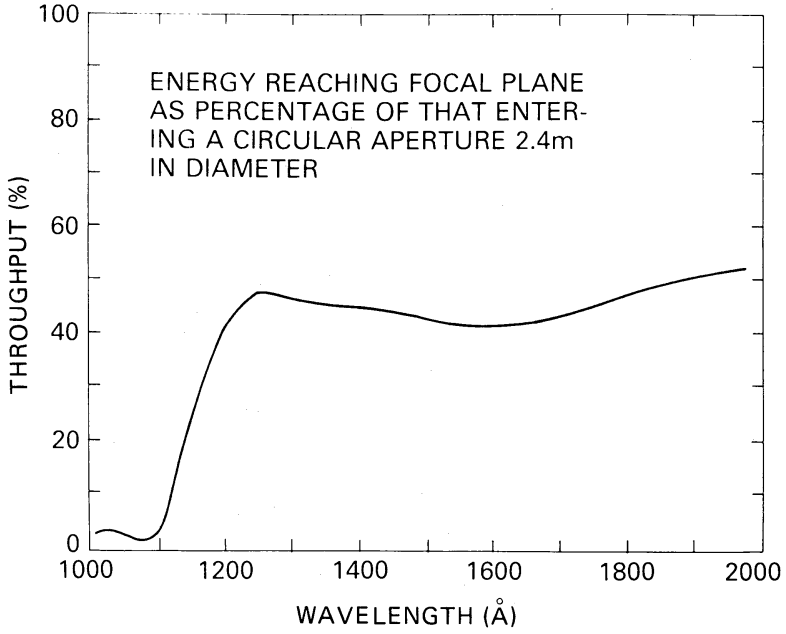
Optical characteristics of HST

Optical design	Ritchey-Chrétien
Aperture	2.4 m
Collecting area	38 993 cm^2
Wavelength coverage (MgF_2-overcoated aluminum)	1150 Å–1 mm
Focal ratio	$f/24$
Plate scale	3.58 arcsec mm^{-1}
Predicted FWHM of on-axis images, including 0″.007 rms pointing jitter:	
1220 Å	0.023 arcsec
2000 Å	0.025 arcsec
3500 Å	0.035 arcsec
4500 Å	0.041 arcsec
6328 Å	0.056 arcsec
Predicted radius of 70% encircled energy (at 6328 Å)	0.10 arcsec

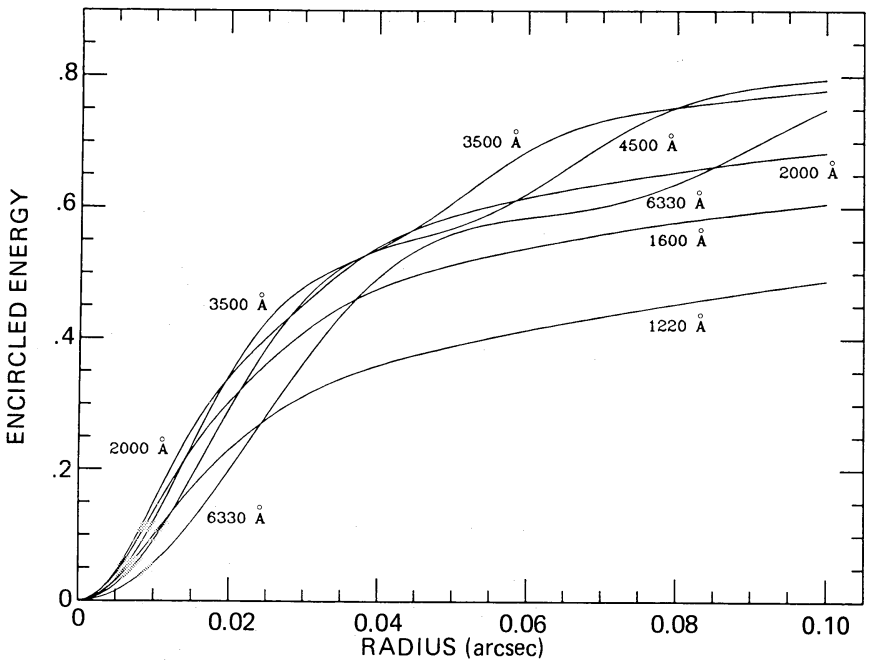
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Description of the Hubble Space Telescope *(cont.)*

Predicted HST throughput.



Predicted on-axis HST encircled energy at various wavelengths.



The following six scientific instruments will be available on HST:

- Wide Field and Planetary Camera (WF/PC)
- Faint Object Camera (FOC)
- Faint Object Spectrograph (FOS)
- High Resolution Spectrograph (HRS)

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Description of the Hubble Space Telescope *(cont.)*

- High Speed Photometer (HSP)
- Fine Guidance Sensors (FGS)

HST instrument capabilities

Direct imaging[1]

Instrument	Field of view	Projected pixel spacing on sky	Wavelength range (Å)	Magnitude limit[2]
WFC	154″ × 154″	0.″10	1150–11 000	28
PC	66″ × 66″	0.″043	1150–11 000	28
FOC *f*/48	44″ × 44″	0.″043	1150–6500	27
f/96	22″ × 22″	0.″022	1150–6500	27
f/288	7.″3 × 7.″3	0.″0072	1150–6500	26

Astrometry

Instrument	Field of view	Positional accuracy	Wavelength range (Å)	Magnitude limit[3]
FGS	69 (arcmin)^2	±0.″0016[4]	4700–7100	17

Photometry

Instrument	Aperture diameters	Time resolution	Wavelength range (Å)	Magnitude limit[5]
HSP[6]	0.″4, 1.″0	10 μs	1200–9000	25

Slitless spectroscopy[7]

Instrument	Projected pixel spacing on sky	Resolving power ($\lambda/\Delta\lambda$)	Wavelength range (Å)	Magnitude limit
WFC	0.″10	100	1600–4000	22[8]
		40	1300–2000	21[8]
		45	3000–6000	23[2]
		35	6000–10 000	23[2]
FOC *f*/48	0.″043	50 at 1500 Å	1150–6000	22[9]
f/96	0.″022	50 at 1500 Å	1150–6000	22[9]

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Description of the Hubble Space Telescope *(cont.)*

HST instrument capabilities (cont.)

Slit spectroscopy

Instrument	Projected aperture size	Resolving power ($\lambda/\Delta\lambda$)	Time resolution	Wavelength range (Å)	Magnitude limit[2]
FOC $f/48$[10]	0.″1 × 20″	2000		1150–1325	18
		2000		1167–1767	18
		2000		1750–2650	20
		2000		3500–5300	21
FOS[11]	0.″1–4.″3	1300	20 ms	1150–8500	18–22–22
		250	20 ms	1150–8500	21–26–23
HRS	0.″25, 2.″0	100 000	50 ms	1150–3200	11–14
		20 000	50 ms	1150–3200	13–16
		2000	50 ms	1150–1800	17

Notes to tables:

[1] The cameras also have coronagraphic and polarimetric imaging capabilities.

[2] Predicted limiting V magnitude for an unreddened A0 V star in order to achieve a S/N ratio of 5 in an exposure time of 1 hour. Single entries refer to wavelengths near the center of the indicated wavelength range. For FOC direct imaging, the F342W filter was assumed. When two values are given, the first refers to wavelengths near the short-wavelength limit, and the second to those near the long-wavelength limit. For FOS spectroscopy, three values are given, corresponding to 1300, 3200, and 6000 Å, respectively.

[3] For $S/N = 1$ in fine lock.

[4] Within the central area of 4′ × 5′. In-orbit performance for astrometry is very uncertain; figure quoted is design goal.

[5] Predicted limiting V magnitude for a 1-hour exposure (half on star, half on sky) on an A0 V star at $S/N = 5$ with the F450W filter.

[6] The HSP can also perform polarimetry.

[7] Using 'objective' gratings or prisms.

[8] Predicted limiting V magnitude for an unreddened B0 V star in order to achieve a S/N ratio of 5 in an exposure time of 1 hour.

[9] Predicted limiting V magnitude for a QSO with a ν^{-2} spectrum in order to achieve a S/N ratio of 10 in an exposure time of 1 hour with the far-UV objective prism (PRISM2).

[10] Two-dimensional spectroscopy with the long slit and grating.

[11] The FOS can also perform spectropolarimetry.

Glossary of astronomical terms

aberration: the apparent angular displacement of the observed position of a celestial object from its *geometric position*, caused by the finite velocity of light in combination with the motions of the observer and of the observed object. (See *aberration, planetary.*)

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aberration, annual: the component of stellar aberration (see *aberration, stellar*) resulting from the motion of the Earth about the Sun.

aberration, diurnal: the component of stellar aberration (see *aberration, stellar*) resulting from the observer's diurnal motion about the center of the Earth.

aberration, E-terms of: terms of annual aberration (*see aberration, annual*) depending on the *eccentricity* and longitude of *perihelion* of the Earth.

aberration, elliptic: see *aberration, E-terms of.*

aberration, planetary: the apparent angular displacement of the observed position of a celestial body produced by motion of the observer (see *aberration, stellar*) and the actual motion of the observed object (see *correction for light-time*).

aberration, secular: the component of stellar aberration (see *aberration, stellar*) resulting from the essentially uniform and rectilinear motion of the entire solar system in space. Secular aberration is usually disregarded.

aberration, stellar: the apparent angular displacement of the observed position of a celestial body resulting from the motion of the observer. Stellar aberration is divided into diurnal, annual and secular components (see *aberration, diurnal; aberration, annual; aberration, secular*).

altitude: the angular distance of a celestial body above or below the *horizon*, measured along the great circle passing through the body and the *zenith*. Altitude is 90° minus *zenith distance*.

aphelion: the point in a planetary *orbit* that is at the greatest distance from the Sun.

apparent place: the position on a *celestial sphere*, centered at the Earth, determined by removing from the directly observed position of a celestial body the effects that depend on the *topocentric* location of the observer; i.e., *refraction*, diurnal aberration (see *aberration, diurnal*) and geocentric (diurnal) *parallax*. Thus the position at which the object would actually be seen from the center of the Earth, displaced by planetary aberration (except the diurnal part – see *aberration, planetary* and *aberration, diurnal*) and referred to the *true equator and equinox*.

apparent solar time: the measure of time based on the diurnal motion of the true Sun. The rate of diurnal motion undergoes seasonal variation because of the *obliquity* of the *ecliptic* and because of the *eccentricity* of the Earth's *orbit*. Additional small variations result from irregularities in the rotation of the Earth on its axis.

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astrometric ephemeris: an ephemeris of a solar system body in which the tabulated positions are essentially comparable to catalog *mean places* of stars at a *standard epoch*. An astrometric position is obtained by adding to the *geometric position*, computed from gravitational theory, the correction for *light-time*. Prior to 1984, the E-terms of annual aberration (see *aberration, annual* and *aberration, E-terms of*) were also added to the geometric position.

astronomical coordinates: the longitude and latitude of a point on the Earth relative to the *geoid*. These coordinates are influenced by local gravity anomalies (see *zenith*.)

astronomical unit (AU): the radius of a circular orbit in which a body of negligible mass, and free of perturbations, would revolve around the Sun in $2\pi/k$ days, where k is the *Gaussian gravitational constant*. This is slightly less than the *semimajor axis* of the Earth's *orbit*.

atomic second: see *second, Système International*.

augmentation: the amount by which the apparent *semidiameter* of a celestial body, as observed from the surface of the Earth, is greater than the semidiameter that would be observed from the center of the Earth.

azimuth: the angular distance measured clockwise along the *horizon* from a specified reference point (usually north) to the intersection with the great circle drawn from the *zenith* through a body on the *celestial sphere*.

barycenter: the center of mass of a system of bodies; e.g., the center of mass of the solar system or the Earth–Moon system.

barycentric dynamical time (TDB): the independent argument of ephemerides and equations of motion that are referred to the *barycenter* of the solar system. A family of time scales results from the transformation by various theories and metrics of relativistic theories of *terrestrial dynamical time* (TDT). TDB differs from TDT only by periodic variations. In the terminology of the general theory of relativity, TDB may be considered to be a coordinate time. (See *dynamical time*.)

catalog equinox: the intersection of the *hour circle* of zero *right ascension* of a star catalog with the *celestial equator*. (See *dynamical equinox* and *equator*.)

celestial ephemeris pole: the reference pole for *nutation* and *polar motion*; the axis of figure for the mean surface of a model Earth in which the free motion has zero amplitude. This pole has no nearly-diurnal nutation with respect to a space-fixed or Earth-fixed coordinate system.

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celestial equator: the projection onto the *celestial sphere* of the Earth's *equator*. (See *mean equator and equinox* and *true equator and equinox*.)

celestial pole: either of the two points projected onto the *celestial sphere* by the extension of the Earth's axis of rotation to infinity.

celestial sphere: an imaginary sphere of arbitrary radius upon which celestial bodies may be considered to be located. As circumstances require, the celestial sphere may be centered at the observer, at the Earth's center, or at any other location.

conjunction: the phenomenon in which two bodies have the same apparent celestial longitude (see *longitude, celestial*) or *right ascension* as viewed from a third body. Conjunctions are usually tabulated as *geocentric* phenomena, however. For Mercury and Venus, geocentric inferior conjunction occurs when the planet is between the Earth and Sun, and superior conjunction occurs when the Sun is between the planet and Earth.

constellation: a grouping of stars, usually with pictorial or mythical associations, that serves to identify an area of the *celestial sphere*. Also one of the precisely defined areas of the celestial sphere, associated with a grouping of stars, that the International Astronomical Union has designated as a constellation.

coordinated universal time (UTC): the time scale available from broadcast time signals. UTC differs from TAI (*see international atomic time*) by an integral number of seconds; it is maintained within ± 0.90 seconds of UT1 (*see universal time*) by the introduction of one second steps (leap seconds).

culmination: passage of a celestial object across the observer's *meridian*; also called 'meridian passage'. More precisely, culmination is the passage through the point of greatest *altitude* in the diurnal path. Upper culmination (also called 'culmination above pole' for circumpolar stars and the Moon) or transit is the crossing closer to the observer's *zenith*. Lower culmination (also called 'culmination below pole' for circumpolar stars and the Moon) is the crossing farther from the zenith.

day: an interval of 86 400 SI seconds (*see second, Système International*), unless otherwise indicated.

day numbers: quantities that facilitate hand calculations of the reduction of *mean place* to *apparent place*. Besselian day numbers depend solely on the Earth's position and motion; second-order day numbers, used in high precision reductions, depend on the positions of both the Earth and the star.

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declination: angular distance on the *celestial sphere* north or south of the *celestial equator*. It is measured along the *hour circle* passing through the celestial object. Declination is usually given in combination with *right ascension* or *hour angle*.

defect of illumination: the angular amount of the observed lunar or planetary disk that is not illuminated to an observer on the Earth.

deflection of light: the angle by which the apparent path of a photon is altered from a straight line by the gravitational field of the Sun. The path is deflected radially away from the Sun by up to 1.″75 at the Sun's limb. Correction for this effect, which is independent of wavelength, is included in the reduction from *mean place* to *apparent place*.

deflection of the vertical: the angle between the astronomical vertical and the geodetic vertical (see *zenith; astronomical coordinates; geodetic coordinates*.)

Delta T (ΔT): the difference between *dynamical time* and *universal time*; specifically the difference between *terrestrial dynamical time* (TDT) and UT1: $\Delta T = TDT - UT1$.

direct motion: for orbital motion in the solar system, motion that is counterclockwise in the orbit as seen from the north pole of the *ecliptic*; for an object observed on the celestial sphere, motion that is from west to east, resulting from the relative motion of the object and the Earth.

DUT1: the predicted value of the difference between UT1 and UTC, transmitted in code on broadcast time signals: DUT1 = UT1 − UTC. (See *universal time* and *coordinated universal time*.)

dynamical equinox: the ascending *node* of the Earth's mean *orbit* on the Earth's *equator*; i.e., the intersection of the *ecliptic* with the *celestial equator* at which the Sun's *declination* is changing from south to north. (See *catalog equinox* and *equinox*.)

dynamical time: the family of time scales introduced in 1984 to replace *ephemeris time* as the independent argument of dynamical theories and ephemerides. (See *barycentric dynamical time* and *terrestrial dynamical time*.)

eccentric anomaly: in undisturbed elliptic motion, the angle measured at the center of the ellipse from *pericenter* to the point on the circumscribing auxiliary circle from which a perpendicular to the major axis would intersect the orbiting body. (See *mean anomaly* and *true anomaly*.)

eccentricity: a parameter that specifies the shape of a conic section; one

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of the standard elements used to describe an elliptic *orbit* (see *elements, orbital*).

eclipse: the obscuration of a celestial body caused by its passage through the shadow cast by another body.

eclipse, annular: a solar *eclipse* (see *eclipse, solar*) in which the solar disk is never completely covered but is seen as an annulus or ring at maximum eclipse. An annular eclipse occurs when the apparent disk of the Moon is smaller than that of the Sun.

eclipse, lunar: an *eclipse* in which the Moon passes through the shadow cast by the Earth. The eclipse may be total (the Moon passing completely through the Earth's *umbra*), partial (the Moon passing partially through the Earth's umbra at maximum eclipse), or penumbral (the Moon passing only through the Earth's *penumbra*).

eclipse, solar: an *eclipse* in which the Earth passes through the shadow cast by the Moon. It may be total (observer in the Moon's *umbra*), partial (observer in the Moon's *penumbra*), or annular (see *eclipse, annular*).

ecliptic: the mean plane of the Earth's *orbit* around the Sun.

elements, Besselian: quantities tabulated for the calculation of accurate predictions of an *eclipse* or *occultation* for any point on or above the surface of the Earth.

elements, orbital: parameters that specify the position and motion of a body in *orbit* (see *osculating elements* and *mean elements.*)

elongation, greatest: the instants when the *geocentric* angular distances of Mercury and Venus are at a maximum from the Sun.

elongation (planetary): the *geocentric* angle between a planet and the Sun, measured in the plane of the planet, Earth and Sun. Planetary elongations are measured from 0° to 180°, east or west of the Sun.

elongation (satellite): the *geocentric* angle between a satellite and its primary, measured in the plane of the satellite, planet and Earth. Satellite elongations are measured from 0° east or west of the planet.

ephemeris hour angle: an *hour angle* referred to the *ephemeris meridian.*

ephemeris longitude: longitude (see *longitude, terrestrial*) measured eastward from the *ephemeris meridian.*

ephemeris meridian: a fictitious *meridian* that rotates independently of the Earth at the uniform rate implicitly defined by *terrestrial dynamical time* (TDT). The ephemeris meridian is $1.002\,738\Delta T$ east of the Greenwich meridian, where $\Delta T = TDT - UT1$.

ephemeris time (ET): the time scale used prior to 1984 as the independent variable in gravitational theories of the solar system. In 1984, ET was replaced by *dynamical time.*

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ephemeris transit: the passage of a celestial body or point across the *ephemeris meridian.*

equation of center: in elliptic motion the *true anomaly* minus the *mean anomaly*. It is the difference between the actual angular position in the elliptic *orbit* and the position the body would have if its angular motion were uniform.

equation of the equinoxes: the *right ascension* of the mean *equinox* (see *mean equator and equinox*) referred to the *true equator and equinox*; apparent *sidereal time* minus mean sidereal time. (See *apparent place* and *mean place.*)

equation of time: the *hour angle* of the true Sun minus the hour angle of the *fictitious mean sun*; alternatively, *apparent solar time* minus *mean solar time.*

equator: the great circle on the surface of a body formed by the intersection of the surface with the plane passing through the center of the body perpendicular to the axis of rotation. (See *celestial equator.*)

equinox: either of the two points on the *celestial sphere* at which the *ecliptic* intersects the *celestial equator*; also the time at which the Sun passes through either of these intersection points; i.e., when the apparent longitude (see *apparent place* and *longitude, celestial*) of the Sun is 0° or 180°. (See *catalog equinox* and *dynamical equinox* for precise usage.)

fictitious mean sun: an imaginary body introduced to define *mean solar time*; essentially the name of a mathematical formula that defined mean solar time. This concept is no longer used in high precision work.

flattening: a parameter that specifies the degree by which a planet's figure differs from that of a sphere,; the ratio $f = (a - b)/a$, where a is the equatorial radius and b is the polar radius.

Gaussian gravitational constant ($k = 0.017\,202\,098\,95$): the constant defining the astronomical system of units of length (*astronomical unit*), mass (solar mass) and time (*day*), by means of Kepler's third law. The dimensions of k^2 are those of Newton's constant of gravitation: $L^3M^{-1}T^{-2}$.

geocentric: with reference to, or pertaining to, the center of the Earth.

geocentric coordinates: the latitude and longitude of a point on the Earth's surface relative to the center of the Earth; also celestial coordinates given with respect to the center of the Earth. (See *zenith; latitude, terrestrial; longitude, terrestrial.*)

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geodetic coordinates: the latitude and longitude of a point on the Earth's surface determined from the geodetic vertical (normal to the specified spheroid). (See *zenith; latitude, terrestrial; longitude, terrestrial.*)

geoid: an equipotential surface that coincides with mean sea level in the open ocean. On land it is the level surface that would be assumed by water in an imaginary network of frictionless channels connected to the ocean.

geometric position: the *geocentric* position of an object on the *celestial sphere* referred to the *true equator and equinox*, but without the displacement due to planetary aberration. (See *apparent place; mean place; aberration, planetary.*)

Greenwich sidereal date (GSD): the number of *sidereal days* elapsed at Greenwich since the beginning of the Greenwich sidereal day that was in progress at *Julian date* 0.0.

Greenwich sidereal day number: the integral part of the *Greenwich sidereal date.*

Gregorian calendar: the calendar introduced by Pope Gregory XIII in 1582 to replace the *Julian calendar*; the calendar now used as the civil calendar in most countries. Every year that is exactly divisible by four is a leap year, except for centurial years, which must be exactly divisible by 400 to be leap years. Thus 2000 is a leap year, but 1900 and 2100 are not leap years.

heliocentric: with reference to, or pertaining to, the center of the Sun.

horizon: a plane perpendicular to the line from an observer to the *zenith.* The great circle formed by the intersection of the *celestial sphere* with a plane perpendicular to the line from an observer to the zenith is called the astronomical horizon.

horizontal parallax: the difference between the *topocentric* and *geocentric* positions of an object, when the object is on the astronomical *horizon.*

hour angle: angular distance on the *celestial sphere* measured westward along the *celestial equator* from the *meridian* to the *hour circle* that passes through a celestial object.

hour circle: a great circle on the *celestial sphere* that passes through the *celestial poles* and is therefore perpendicular to the *celestial equator.*

inclination: the angle between two planes or their poles; usually the angle between an orbital plane and a reference plane; one of the standard orbital elements (see *elements, orbital*) that specifies the orientation of an *orbit.*

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international atomic time (TAI): the continuous scale resulting from analyses by the Bureau International des Poids et Mésures of atomic time standards in many countries. The fundamental unit of TAI is the SI second (see *second, Système International*), and the epoch is 1958 January 1.

invariable plane: the plane through the center of mass of the solar system perpendicular to the angular momentum vector of the solar system.

irradiation: an optical effect of contrast that makes bright objects viewed against a dark background appear to be larger than they really are.

Julian calendar: the calendar introduced by Julius Caesar in 46 BC to replace the Roman calendar. In the Julian calendar a common year is defined to comprise 365 days, and every fourth year is a leap year comprising 366 days. The Julian calendar was superseded by the *Gregorian calendar.*

Julian date (JD): the interval of time in days and fraction of a day since 1 January 4713 BC, Greenwich noon, *Julian proleptic calendar.* In precise work the time scale, e.g., *dynamical time* or *universal time*, should be specified.

Julian date, modified (MJD): the Julian date minus 240 0000.5.

Julian day number (JD): the integral part of the *Julian date.*

Julian proleptic calendar: the calendric system employing the rules of the *Julian calendar*, but extended and applied to dates preceding the introduction of the Julian calendar.

Julian year: a period of 365.25 days. This period served as the basis for the *Julian calendar.*

Laplacian plane: for planets *see invariable plane*; for a system of satellites, the fixed plane relative to which the vector sum of the disturbing forces has no orthogonal component.

latitude, celestial: angular distance on the *celestial sphere* measured north or south of the *ecliptic* along the great circle passing through the poles of the ecliptic and the celestial object.

latitude, terrestrial: angular distance on the Earth measured north or south of the *equator* along the *meridian* of a geographic location.

librations: variations in the orientation of the Moon's surface with respect to an observer on the Earth. Physical librations are due to variations in the rate at which the Moon rotates on its axis. The much larger optical librations are due to variations in the rate of the Moon's orbital motion, the *obliquity* of the Moon's *equator* to its

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orbital plane, and the diurnal changes of geometric perspective of an observer on the Earth's surface.

light-time: the interval of time required for light to travel from a celestial body to the Earth. During this interval the motion of the body in space causes an angular displacement of its *apparent place* from its *geometric position* (see *aberration, planetary*).

light year: the distance that light traverses in a vacuum during one year.

local sidereal time: the local *hour angle* of a *catalog equinox.*

longitude, celestial: angular distance on the *celestial sphere* measured eastward along the *ecliptic* from the *dynamical equinox* to the great circle passing through the poles of the ecliptic and the celestial object.

longitude, terrestrial: angular distance measured along the Earth's *equator* from the Greenwich *meridian* to the meridian of a geographic location.

lunar phases: cyclically recurring apparent forms of the Moon. New Moon, First Quarter, Full Moon and Last Quarter are defined as the times at which the excess of the apparent celestial longitude (see *longitude, celestial*) of the Moon over that of the Sun is 0°, 90°, 180° and 270°, respectively.

lunation: the period of time between two consecutive New Moons.

magnitude, stellar: a measure on a logarithmic scale of the brightness of a celestial object considered as a point source.

magnitude of a lunar eclipse: the fraction of the lunar diameter obscured by the shadow of the Earth at the greatest phase of a lunar eclipse (see *eclipse, lunar*), measured along the common diameter.

magnitude of a solar eclipse: the fraction of the solar diameter obscured by the Moon at the greatest phase of a solar eclipse (*see eclipse, solar*), measured along the common diameter.

mean anomaly: in undisturbed elliptic motion, the product of the *mean motion* of an orbiting body and the interval of time since the body passed *pericenter.* Thus the mean anomaly is the angle from pericenter of a hypothetical body moving with a constant angular speed that is equal to the mean motion. (See *true anomaly* and *eccentric anomaly.*)

mean distance: the *semimajor axis* of an elliptic *orbit.*

mean elements: elements of an adopted reference *orbit* (see *elements, orbital*) that approximates the actual, perturbed orbit. Mean elements may serve as the basis for calculating *perturbations.*

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mean equator and equinox: the celestial reference system determined by ignoring small variations of short period in the motions of the *celestial equator*. Thus the mean equator and equinox are affected only by *precession*. Positions in star catalogs are normally referred to the mean catalog equator and equinox (see *catalog equinox*) of a *standard epoch*.

mean motion: in undisturbed elliptic motion, the constant angular speed required for a body to complete one revolution in an *orbit* of a specified *semimajor axis*.

mean place: the coordinates, referred to the *mean equator and equinox* of a *standard epoch*, of an object on the *celestial sphere* centered at the Sun. A mean place is determined by removing from the directly observed position the effects of *refraction*, geocentric and stellar *parallax*, and stellar aberration (see *aberration, stellar*), and by referring the coordinates to the mean equator and equinox of a standard epoch. In compiling star catalogs it has been the practice not to remove the secular part of stellar aberration (see *aberration, secular*). Prior to 1984, it was additionally the practice not to remove the elliptic part of annual aberration (see *aberration, annual* and *aberration, E-terms of*).

mean solar time: a measure of time based conceptually on the diurnal motion of the *fictitious mean sun*, under the assumption that the Earth's rate of rotation is constant.

meridian: a great circle passing through the *celestial poles* and through the *zenith* of any location on Earth. For planetary observations a meridian is half the great circle passing through the planet's poles and through any location on the planet.

moonrise, moonset: the times at which the apparent upper limb of the Moon is on the astronomical *horizon*; i.e., when the true *zenith distance*, referred to the center of the Earth, of the central point of the disk is $90° 34' + s - \pi$, where s is the Moon's semidiameter, π is the *horizontal parallax*, and $34'$ is the adopted value of horizontal *refraction*.

nadir: the point on the *celestial sphere* diametrically opposite to the *zenith*.

node: either of the points on the *celestial sphere* at which the plane of an *orbit* intersects a reference plane. The position of a node is one of the standard orbital elements (see *elements, orbital*) used to specify the orientation of an orbit.

nutation: the short-period oscillations in the motion of the pole of rotation of a freely rotating body that is undergoing torque from

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external gravitational forces. Nutation of the Earth's pole is discussed in terms of components in *obliquity* and longitude (see *longitude, celestial*).

obliquity: in general the angle between the equatorial and orbital planes of a body or, equivalently, between the rotational and orbital poles. For the Earth the obliquity of the *ecliptic* is the angle between the planes of the *equator* and the ecliptic.

occultation: the obscuration of one celestial body by another of greater apparent diameter; especially the passage of the Moon in front of a star or planet, or the disappearance of a satellite behind the disk of its primary. If the primary source of illumination of a reflecting body is cut off by the occultation, the phenomenon is also called an *eclipse*. The occultation of the Sun by the Moon is a solar eclipse (see *eclipse, solar*).

opposition: a configuration of the Sun, Earth and a planet in which the apparent *geocentric* longitude (see *longitude, celestial*) of the planet differs by 180° from the apparent geocentric longitude of the Sun.

orbit: the path in space followed by a celestial body.

osculating elements: a set of parameters (see *elements, orbital*) that specifies the instantaneous position and velocity of a celestial body in its perturbed *orbit*. Osculating elements describe the unperturbed (two-body) orbit that the body would follow if *perturbations* were to cease instantaneously.

parallax: the difference in apparent direction of an object as seen from two different locations; conversely the angle at the object that is subtended by the line joining two designated points. Geocentric (diurnal) parallax is the difference in direction between a *topocentric* observation and a hypothetical *geocentric* observation. Heliocentric or annual parallax is the difference between hypothetical geocentric and *heliocentric* observations; it is the angle subtended at the observed object by the *semimajor axis* of the Earth's *orbit*. (See also *horizontal parallax*.)

parsec: the distance at which one *astronomical unit* subtends an angle of one second of arc; equivalently the distance to an object having an annual *parallax* of one second of arc.

penumbra: the portion of a shadow in which light from an extended source is partially but not completely cut off by an intervening body; the area of partial shadow surrounding the *umbra*.

pericenter: the point in an *orbit* that is nearest to the center of force. (See *perigee* and *perihelion*.)

perigee: the point at which a body in *orbit* around the Earth most

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closely approaches the Earth. Perigee is sometimes used with reference to the apparent orbit of the Sun around the Earth.

perihelion: the point at which a body in *orbit* around the Sun most closely approaches the Sun.

period: the interval of time required to complete one revolution in an *orbit* or one cycle of a periodic phenomenon, such as a cycle of *phases*.

perturbations: deviations between the actual *orbit* of a celestial body and an assumed reference orbit; also the forces that cause deviations between the actual and reference orbits. Perturbations, according to the first meaning, are usually calculated as quantities to be added to the coordinates of the reference orbit to obtain the precise coordinates.

phase: the ratio of the illuminated area of the apparent disk of a celestial body to the area of the entire apparent disk taken as a circle. For the Moon, phase designations (see *lunar phases*) are defined by specific configurations of the Sun, Earth and Moon. For eclipses phase designations (total, partial, penumbral, etc.) provide general descriptions of the phenomena (see *eclipse, solar; eclipse, annular; eclipse, lunar*.)

phase angle: the angle measured at the center of an illuminated body between the light source and the observer.

polar motion: the irregularly varying motion of the Earth's pole of rotation with respect to the Earth's crust. (See *celestial ephemeris pole*.)

precession: the uniformly progressing motion of the pole of rotation of a freely rotating body undergoing torque from external gravitational forces. In the case of the Earth, the component of precession caused by the Sun and Moon acting on the Earth's equatorial bulge is called lunisolar precession; the component caused by the action of the planets is called planetary precession. The sum of lunisolar and planetary precession is called general precession. (See *nutation*.)

proper motion: the projection onto the *celestial sphere* of the space motion of a star relative to the solar system; thus the transverse component of the space motion of a star with respect to the solar system. Proper motion is usually tabulated in star catalogs as changes in *right ascension* and *declination* per year or century.

quadrature: a configuration in which two celestial bodies have apparent longitudes (see *longitude, celestial*) that differ by 90° as viewed from a third body. Quadratures are usually tabulated with respect to the Sun as viewed from the center of the Earth.

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radial velocity: the rate of change of the distance to an object.

refraction, astronomical: the change in direction of travel (bending) of a light ray as it passes obliquely through the atmosphere. As a result of refraction the observed *altitude* of a celestial object is greater than its geometric altitude. The amount of refraction depends on the altitude of the object and on atmospheric conditions.

retrograde motion: for orbital motion in the solar system, motion that is clockwise in the *orbit* as seen from the north pole of the *ecliptic*; for an object observed on the *celestial sphere*, motion that is from east to west, resulting from the relative motion of the object and the Earth. (See *direct motion.*)

right ascension: angular distance on the *celestial sphere* measured eastward along the *celestial equator* from the *equinox* to the *hour circle* passing through the celestial object. Right ascension is usually given in combination with *declination.*

second, Système International (SI): the duration of 9 192 631 770 cycles of radiation corresponding to the transition between two hyperfine levels of the ground state of cesium 133.

selenocentric: with reference to, or pertaining to, the center of the Moon.

semidiameter: the angle at the observer subtended by the equatorial radius of the Sun, Moon or a planet.

semimajor axis: half the length of the major axis of an ellipse; a standard element used to describe an elliptical *orbit* (see *elements, orbital*).

sidereal day: the interval of time between two consecutive *transits* of the *catalog equinox.* (See *sidereal time.*)

sidereal hour angle: angular distance on the *celestial sphere* measured westward along the *celestial equator* from the *catalog equinox* to the *hour circle* passing through the celestial object. It is equal to 360° minus *right ascension* in degrees.

sidereal time: the measure of time defined by the apparent diurnal motion of the *catalog equinox*; hence a measure of the rotation of the Earth with respect to the stars rather than the Sun.

solstice: either of the two points on the *ecliptic* at which the apparent longitude (see *longitude, celestial*) of the Sun is 90° or 270°; also the time at which the Sun is at either point.

standard epoch: a date and time that specifies the reference system to which celestial coordinates are referred. Prior to 1984 coordinates of star catalogs were commonly referred to the *mean equator and equinox* of the beginning of a Besselian year (see *year, Besselian*).

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Beginning with 1984 the *Julian year* has been used, as denoted by the prefix J, e.g., J2000.0.

stationary point (of a planet): the position at which the rate of change of the apparent *right ascension* (see *apparent place*) of a planet is momentarily zero.

sunrise, sunset: the times at which the apparent upper limb of the Sun is on the astronomical *horizon*; i.e., when the true *zenith distance*, referred to the center of the Earth, of the central point of the disk is 90° 50′, based on adopted values of 34′ for horizontal *refraction* and 16′ for the Sun's *semidiameter*.

surface brightness (of a planet): the visual magnitude of an average square arc-second area of the illuminated portion of the apparent disk.

synodic period: for planets, the mean interval of time between successive *conjunctions* of a pair of planets, as observed from the Sun; for satellites, the mean interval between successive conjunctions of a satellite with the Sun, as observed from the satellite's primary.

terrestrial dynamical time (TDT): the independent argument for apparent *geocentric* ephemerides. At 1977 January $1^{d}\,00^{h}\,00^{m}\,00^{s}$ TAI, the value of TDT was exactly 1977 January $1^{d}.000\,3725$. The unit of TDT is 86 400 SI seconds at mean sea level. For practical purposes TDT = TAI + $32^{s}.184$. (See *barycentric dynamical time; dynamical time; international atomic time.*)

terminator: the boundary between the illuminated and dark areas of the apparent disk of the Moon, a planet or a planetary satellite.

topocentric: with reference to, or pertaining to, a point on the surface of the Earth, usually with reference to a coordinate system.

transit: the passage of a celestial object across a *meridian*; also the passage of one celestial body in front of another of greater apparent diameter (e.g., the passage of Mercury or Venus across the Sun or Jupiter's satellites across its disk); however, the passage of the Moon in front of the larger apparent Sun is called an annular eclipse (see *eclipse, annular*). The passage of a body's shadow across another body is called a shadow transit; however, the passage of the Moon's shadow across the Earth is called a solar eclipse (see *eclipse, solar*).

true anomaly: the angle, measured at the focus nearest the *pericenter* of an elliptical *orbit*, between the pericenter and the radius vector from the focus to the orbiting body; one of the standard orbital elements (see *elements, orbital*). (See also *eccentric anomaly, mean anomaly.*)

true equator and equinox: the celestial coordinate system determined by the instantaneous positions of the *celestial equator* and *ecliptic*. The

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motion of this system is due to the progressive effect of *precession* and the short-term, periodic variations of *nutation*. (See *mean equator and equinox*.)

twilight: the interval of time preceding sunrise and following sunset (*see sunrise, sunset*) during which the sky is partially illuminated. Civil twilight comprises the interval when the *zenith distance*, referred to the center of the Earth, of the central point of the Sun's disk is between 90° 50′ and 96°, nautical twilight comprises the interval from 96° to 102°, astronomical twilight comprises the interval from 102° to 108°.

umbra: the portion of a shadow cone in which none of the light from an extended light source (ignoring *refraction*) can be observed.

universal time (UT): a measure of time that conforms, within a close approximation, to the mean diurnal motion of the Sun and serves as the basis of all civil timekeeping. UT is formally defined by a mathematical formula as a function of *sidereal time*. Thus UT is determined from observations of the diurnal motions of the stars. The time scale determined directly from such observations is designated UT0; it is slightly dependent on the place of observation. When UT0 is corrected for the shift in longitude of the observing station caused by *polar motion*, the time scale UT1 is obtained.

vernal equinox: the ascending *node* of the *ecliptic* on the *celestial equator*; also the time at which the apparent longitude (*see apparent place* and *longitude, celestial*) of the Sun is 0°. (See *equinox*.)

vertical: apparent direction of gravity at the point of observation (normal to the plane of a free level surface).

year: a period of time based on the revolution of the Earth around the Sun. The calendar year (*see Gregorian calendar*) is an approximation to the tropical year (*see year, tropical*). The anomalistic year is the mean interval between successive passages of the Earth through *perihelion*. The sidereal year is the mean period of revolution with respect to the background stars. (See *Julian year* and *year, Besselian*.)

year, Besselian: the period of one complete revolution in *right ascension* of the *fictitious mean sun*, as defined by Newcomb. The beginning of a Besselian year, traditionally used as a *standard epoch*, is denoted by the suffix '.0'. Since 1984 standard epochs have been defined by the *Julian year* rather than the Besselian year. For distinction, the beginning of a Besselian year is now identified by the prefix B (e.g., B1950.0).

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year, tropical: the period of one complete revolution of the mean longitude of the Sun with respect to the *dynamical equinox*. The tropical year is longer than the Besselian year (see *year, Besselian*) by $0^{s}.148T$, where T is centuries from B1900.0.

zenith: in general, the point directly overhead on the *celestial sphere*. The astronomical zenith is the extension to infinity of a plumb line. The geocentric zenith is defined by the line from the center of the Earth through the observer. The geodetic zenith is the normal to the geodetic ellipsoid or spheroid at the observer's location. (See *deflection of the vertical.*)

zenith distance: angular distance on the *celestial sphere* measured along the great circle from the *zenith* to the celestial object. Zenith distance is 90° minus *altitude*.

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