Chapter 5

Ultraviolet astronomy

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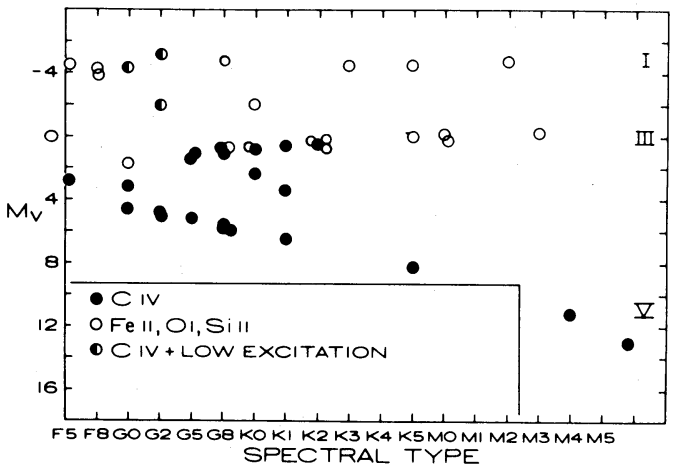
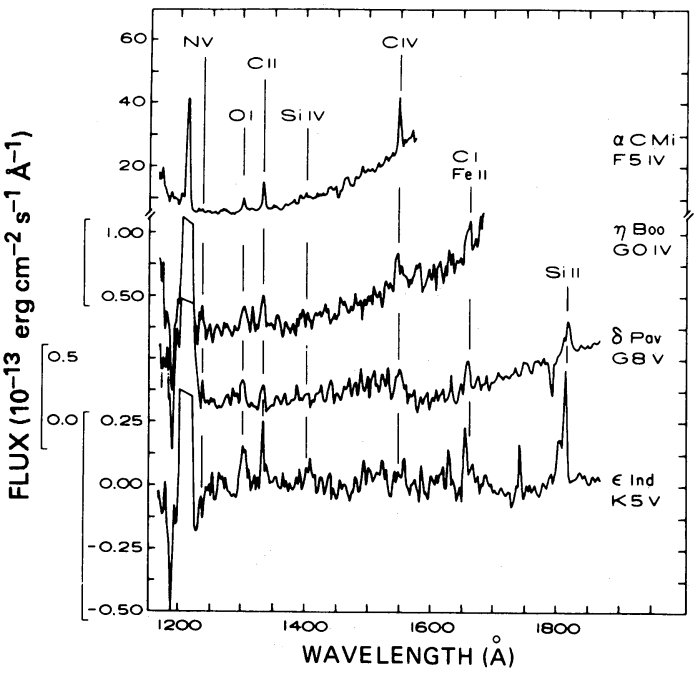
Spectral features in stars of different spectral types and luminosities. (Courtesy of A. K. Dupree, Center for Astrophysics.)



IUE short wavelength spectra of dwarf stars. (Courtesy of A. K. Dupree, Center for Astrophysics.)



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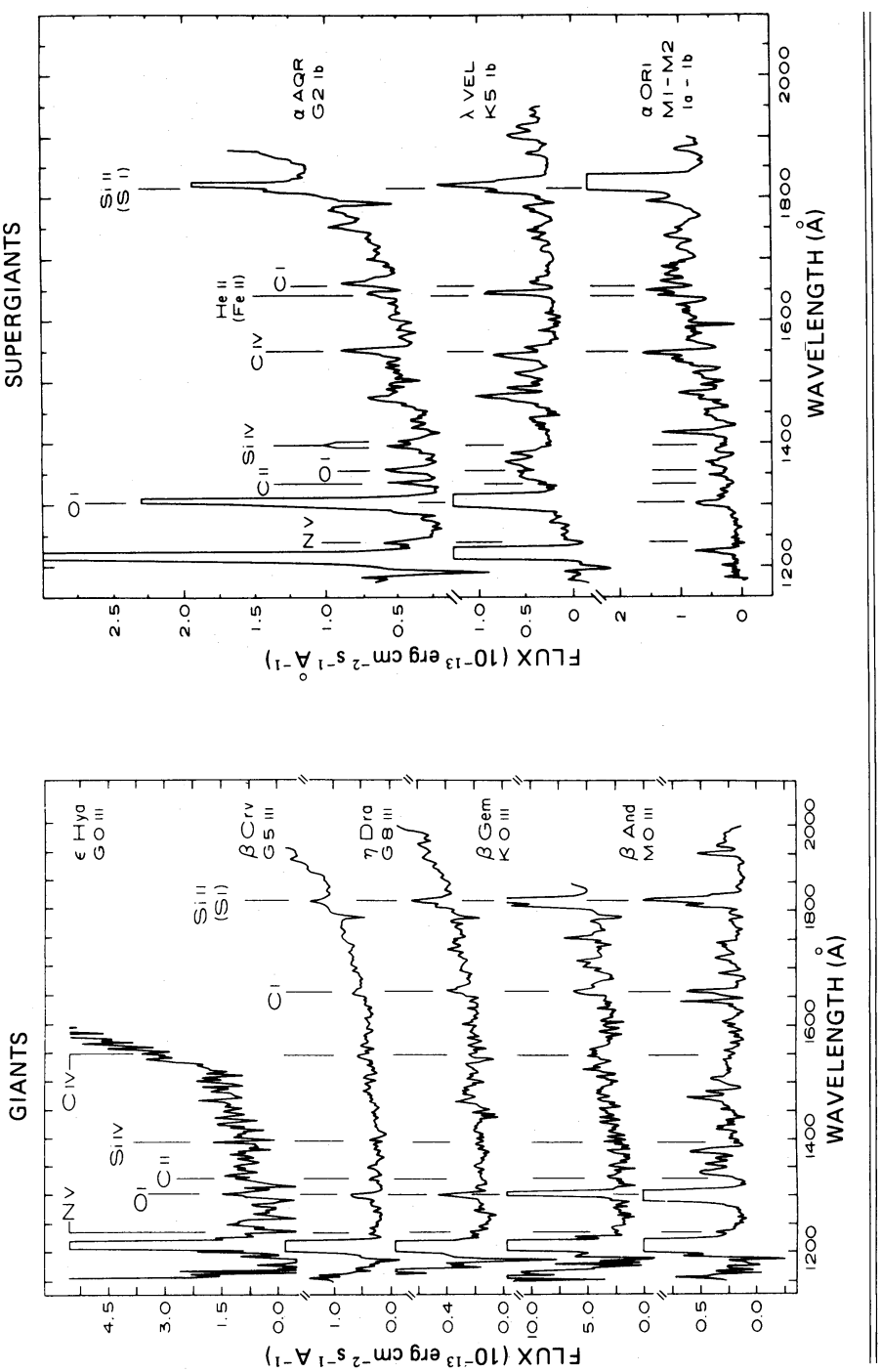
UV stellar spectra (*cont.*) IUE short wavelength spectra of giant and supergiant stars. (Courtesy of A. K. Dupree, Harvard/Smithsonian Center for Astrophysics)



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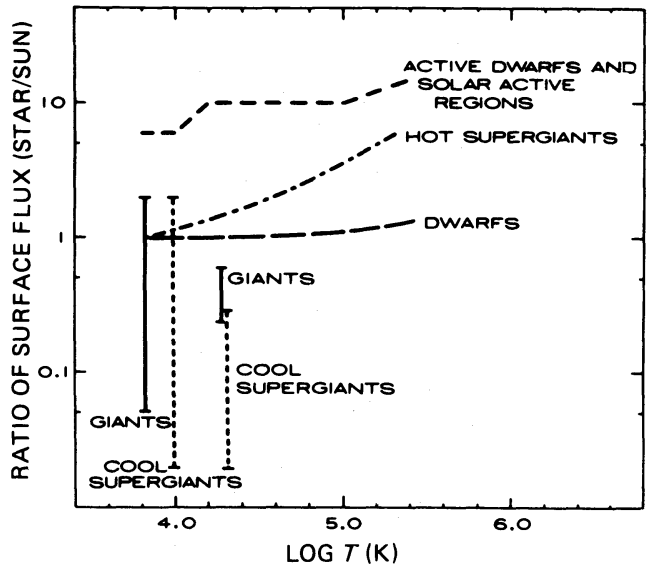
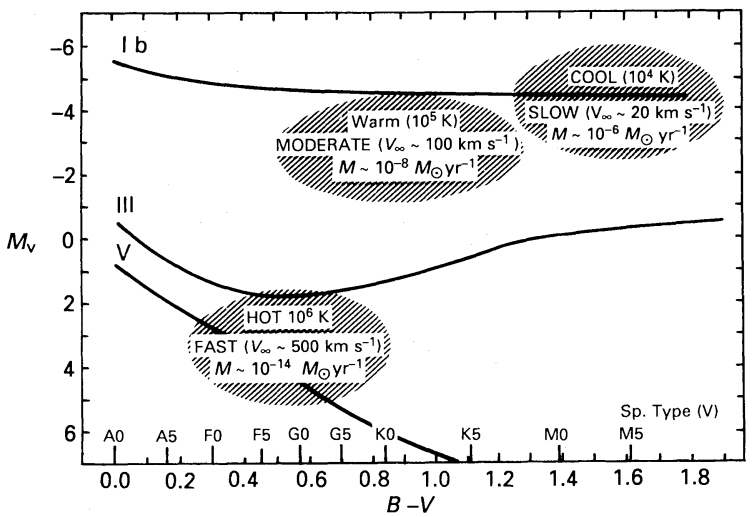
Stellar surface fluxes

The ratio of stellar surface flux to the corresponding solar value for emission lines formed at various temperatures. (Courtesy of A. K. Dupree, Harvard/Smithsonian Center for Astrophysics.)



Mass loss rates

Characteristics of mass loss rates and winds (temperatures and terminal velocities) in stars of various luminosities. (Courtesy of A. K. Dupree, Harvard/Smithsonian Center for Astrophysics.)



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Stellar EUV sources ($\lesssim 5\%$ of sky surveyed)

Source	α 1950	δ 1950	Distance (pc)	Flux (erg cm^{-2} s^{-1}) 500–780 Å	170–620 Å	50–150 Å	Type
HZ 43	$13^h\,14^m$	+29°22′	65 ± 15	—	4×10^{-9}	1.1×10^{-9}	DA White Dwarf
Feige 24	2 32	+2 12	$80 + 50 - 25$	—	3×10^{-9}	—	DA White Dwarf
Proxima Centauri	14 26	−62 28	1.3	—	—	7×10^{-10}	Flare Star
SS Cygni	21 40	+43 21	$30 - 50$	—	—	9×10^{-11}	Dwarf Nova
HD 192273?	20 14	−69 45	—	7×10^{-10}	—	—	B Star
VW Hyi?	4 40	−71	—	—	—	1.3×10^{-9}	U Gem
Feige 4?	0 17	+13 36	70	6×10^{-11}	—	—	DB White Dwarf

(Adapted from Paresce, F. in *Astrophysics from Spacelab*, P. L. Bernacca & R. Ruffini, D. Reidel Publishing Co., Dordrecht, 1980.)

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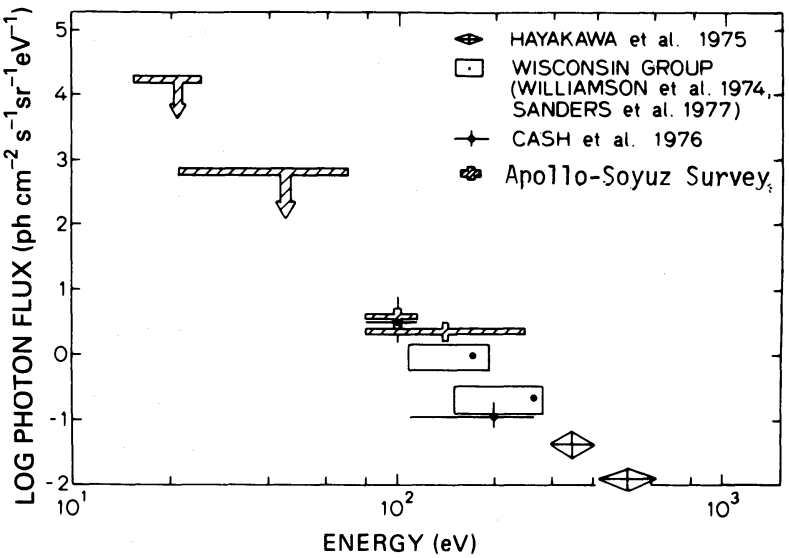
Background fluxes

Cosmic background

Soft X-ray and EUV background fluxes. (Adapted from Stern, R. & Bowyer, S., *Ap. J.*, **230**, 755, 1979.)



Geocoronal vacuum ultraviolet emission

		Photon radiance (ph cm^{-2} s^{-1} sr^{-1})	
λ (Å)	Line	Day	Night
304	He II	8.0×10^5	8.0×10^5
584	He I	8.0×10^7	8.0×10^5
834	O II	8.0×10^7	2.0×10^6
1025	H I	1.6×10^8	1.6×10^8
1216	H I	8.0×10^8	8.0×10^8
1304–1356	O I	8.0×10^8	8.0×10^6
1356–1600	N_2	2.4×10^7	2.4×10^7

1 Rayleigh $= \frac{1}{4\pi} \times 10^6$ ph cm^{-2} s^{-1} sr^{-1}.

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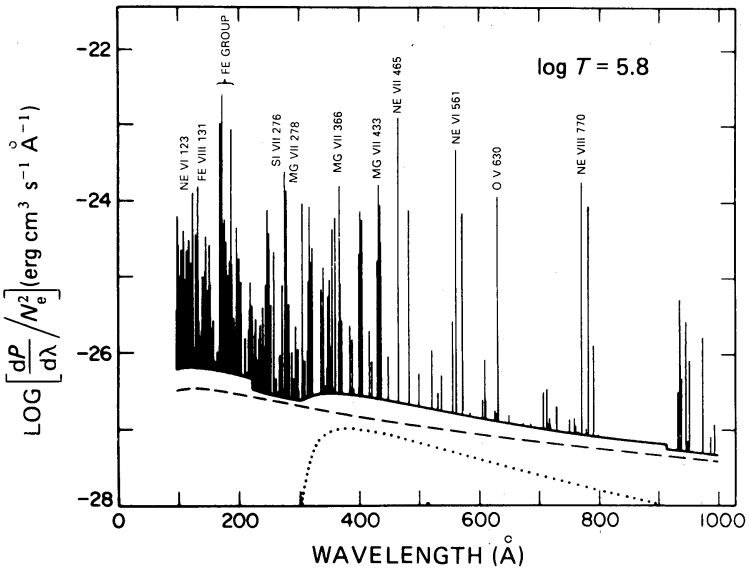
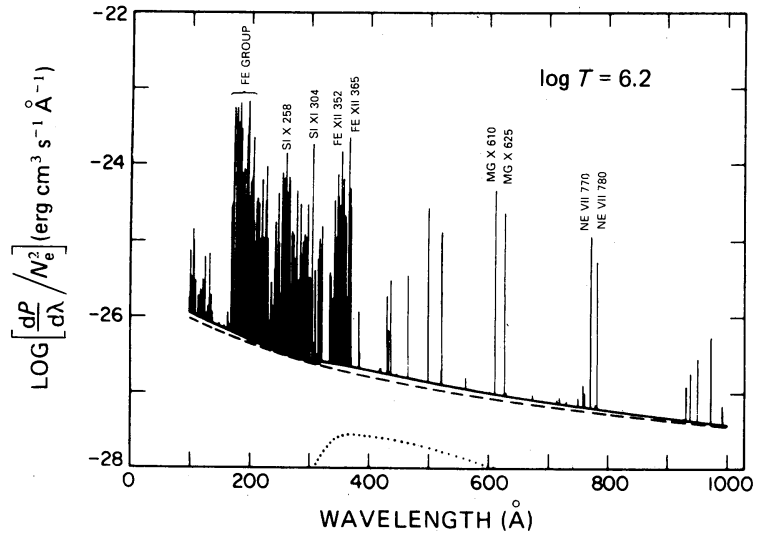
EUV plasma spectra

EUV (100–1000 Å) spectrum of an optically thin plasma. Line fluxes are normalized assuming a line width of 1 Å. Logarithmic abundances: H ≡ 12.00, He = 10.93, C = 8.52, N = 7.96, O = 8.82, Ne = 7.92, Mg = 7.42, Si = 7.52, S = 7.20, Fe = 7.60. Dashed curve: free-free continuum; dotted curve: two-photon continuum; solid curve: total continuum including free-bound radiation. (Adapted from Stern, R., Wang, E. & Bowyer, S., *Ap. J. Suppl.*, **37**, 195, 1978.)





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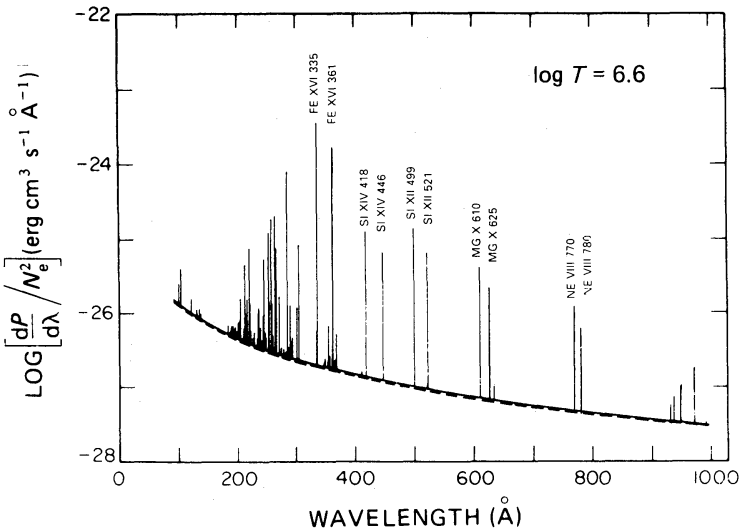
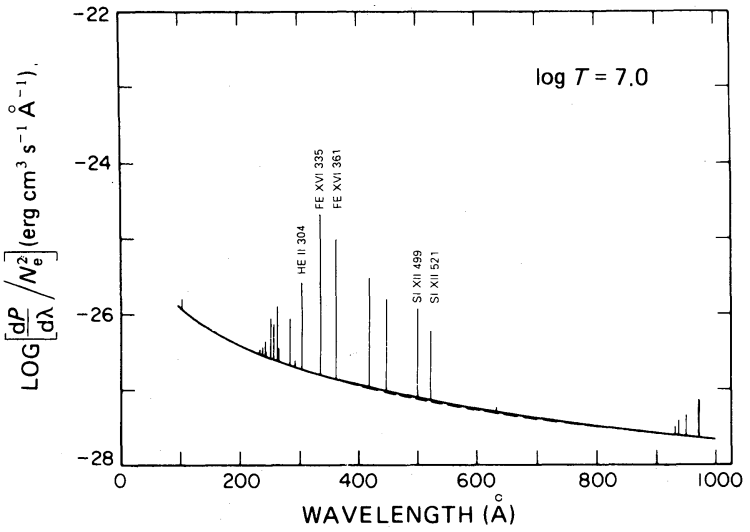
EUV plasma spectra (*cont.*)





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An incomplete list of astrophysically important ultraviolet spectral features

Identification	Wavelength (Å)†	Identification	Wavelength (Å)†
[Ne III]	3869	H I, D I	973
[O II]	3727	H I, D I	950
[Ne V]	3426	N II	917
Mg II	2798	H I, D I Ly edge	912
V II	2326	N II	916
C III	1909	O II	834
O III	1663	O III	834
He II	1640	O II	833
C IV	1549	O III	833
O IV	1402	S IV	816
Si IV	1397	O V	760
C II	1335	S IV	745
O I	1302	O II	719
Si II	1264	O II	718
S II	1260	O III	704
N V	1240	S IV	657
H I, D I	1216	O V	630
S III	1207	O III	600
N I	1201	He I	584
N I	1200	O IV	555
Si II	1190	O IV	554
C III	1176	O IV	553
O III	1175	O II	539
Fe II	1145	He I	537
N I	1134	He I	522
N II	1085	O III	508
N II	1084	O III	507
Ar I	1067	He I cont. edge	504
Si IV	1067	Ne VII	465
H_2	1062	Mg IX	368
H_2	1050	O III	306
H_2	1049	He II	304
O VI	1038	Si XI	303
O II	1036	Fe XV	284
O VI	1032	He II	256
H I, D I	1026	Fe XXIV	255
N III	992	He II	243
N III	990	He II cont. edge	227
C III	977	O V	172

† $h\nu$ (ev) = 12 399/λ (Å).
Brackets denote forbidden transitions.

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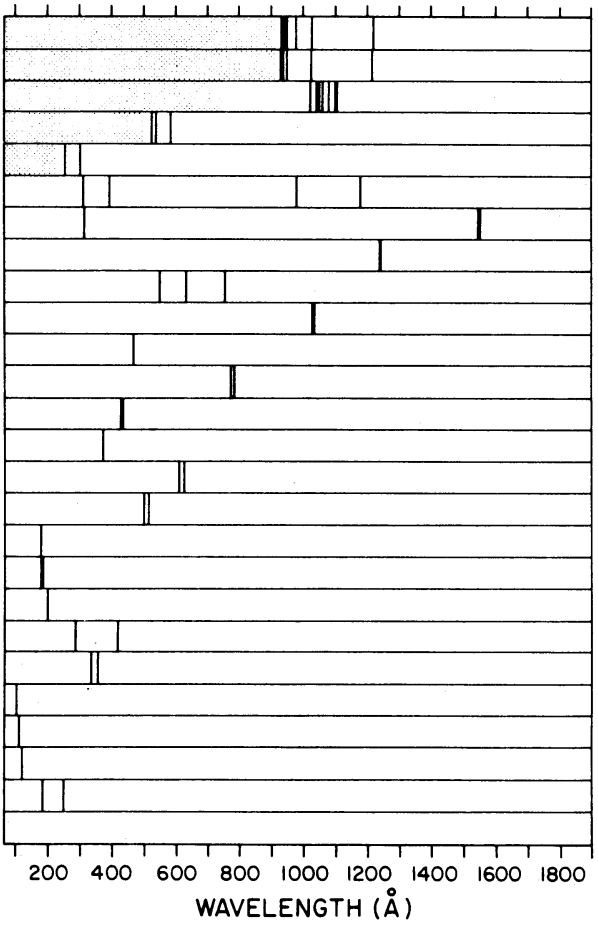
Important strong lines

Wavelengths of important spectral lines of abundant elements and molecular hydrogen (H_2). Also indicated are the typical element abundances on a logarithmic scale where hydrogen is 12.00, and the temperatures of maximum fractional amount of each ion assuming collisional ionization equilibrium. Regions of continuous absorption by photoionization are indicated for hydrogen and helium. (From *FUSE Science Working Group Report*, NASA, 1983.)

SPECIES	LOG *N*	LOG *T*
H I	12.00	4.0
D I	7.2	4.0
H_2	6.0 – 11.7	1.9
He I	11.00	4.3
He II	11.00	4.3
C III	8.57	4.9
C IV	8.57	5.1
N V	8.06	5.3
O V	8.83	5.5
O VI	8.83	5.5
Ne VII	7.45	5.8
Ne VIII	7.45	5.9
Mg VIII	7.54	6.1
Mg IX	7.54	6.1
Mg X	7.54	6.2
Si XII	7.55	6.5
Fe IX	7.40	<6.0
Fe X		6.2
Fe XII		6.4
Fe XV		6.6
Fe XVI		6.8
Fe XVIII		7.1
Fe XIX		7.2
Fe XXI		7.2
Fe XXIV		7.5



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Ultraviolet absorption cross-sections

λ (Å)	Line identification	Absorption cross-sections (10^{-18} cm^2) O	O_2	N_2
1215	Ly α	0	0.01	0.000 03
1176	C III	0	1.30	0
1085	N II	0	2.00	0
1038	O VI	0	0.78	0.0007
1032	O VI	0	1.04	0.0007
1026	Ly β	0	1.58	0.0001
977	C III	0	4.0	0.7
897	Ly cont	2.9	13.0	~11.0
870	Ly cont	2.9	13.0	~10.0
800	Ly cont	2.9	29.0	~10.0
791	O IV	3.2	28.0	25.0
703	O III	7.0	25.0	26.0
630	O V	12.0	30.0	24.0
625	Mg X	12.0	25.0	24.0
584	He I	13.0	23.0	23.0
554	O IV	13.0	26.0	25.0
537	He I	12.0	21.0	25.0
504	He I	12.0	25.0	~22.0
499	Si XII	12.0	25.0	~22.0
465	Ne VII	11.0	23.0	23.0
368	Mg IX	9.0	18.0	16.0
335	Fe XVI	8.8	17.0	14.0
304	He II	9.0	17.0	12.0
284	Fe XV	7.7	15.0	9.8

(Adapted from Sullivan, J. O. & Holland, A. C., NASA CR-371, 1964.)

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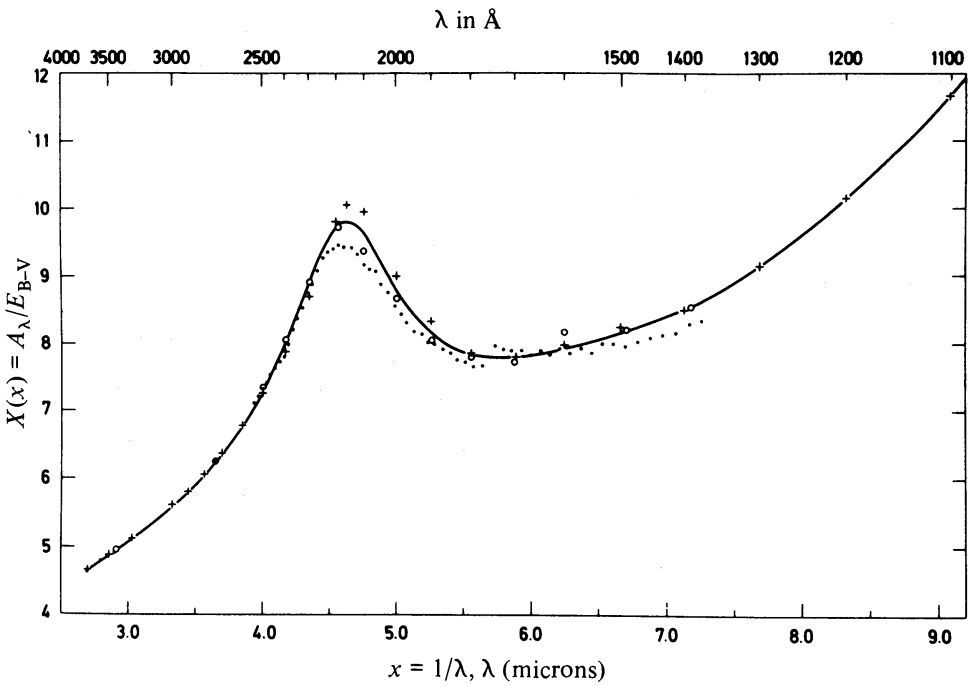
The UV extinction $X(x) = A_\lambda / E_{B-V}$ against $x = 1/\lambda$ in microns. A_λ is the extinction in magnitudes; $E_{B-V} = A_B - A_V$ where A_B and A_V are the extinctions at the wavelengths of the B and V filters. The curve is from the analytical fit of the table below. (Figure courtesy of M. J. Seaton, University College London.)



Analytical fit to the UV extinction (see figure above)

Range of $1/\lambda(\mu) = x$	$A_\lambda / E(B-V) = X$
$2.70 \leqslant 1/\lambda \leqslant 3.65$	$1.56 + 1.048/\lambda + 1.01/\{(1/\lambda - 4.60)^2 + 0.280\}$
$3.65 \leqslant 1/\lambda \leqslant 7.14$	$2.29 + 0.848/\lambda + 1.01/\{(1/\lambda - 4.60)^2 + 0.280\}$
$7.14 \leqslant 1/\lambda \leqslant 10.0$	$16.17 - 3.20/\lambda + 0.2975/\lambda^2$

(From Seaton, M. J., *M.N.R.A.S.*, **187**, 1979.)

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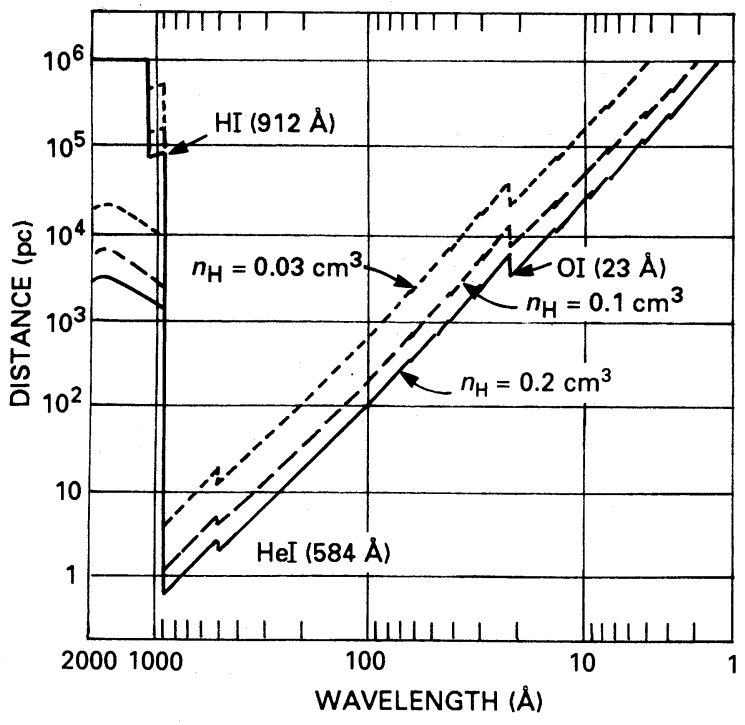
Interstellar EUV attenuation

Distances (parsecs) corresponding to unit optical depth (1/e attenuation) as a function of neutral hydrogen density and wavelength

λ (Å)	$n_{HI} = 1$ (cm^{-3})	$n_{HI} = 0.1$ (cm^{-3})	$n_{HI} = 0.01$ (cm^{-3})	$n_{HI} = 0.001$ (cm^{-3})
912	0.05	0.5	5	50
500	0.2	2	20	200
200	1.5	15	150	1500
100	10	100	1000	10 000

(From FUSE Science Working Group Report, NASA, 1983.)

Distance at which the attenuation of EUV radiation reaches 90%. An ionized interstellar medium of normal composition is assumed. (Adapted from Paresce, F. in *Astrophysics from Spacelab*, P. L. Bernacca & R. Ruffini, eds., D. Reidel Pub. Co., 1980.)



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Average interstellar hydrogen densities within 100 pc

In the direction of	Distance (pc)	n_{HI} (cm^{-3})
Sun	—	0.05
α Cen	1.34	0.06–0.30
ε Eri	3.3	0.06–0.20
ε Ind	3.4	~0.1
α CMi	3.5	0.09–0.13
β Gem	10.8	0.02–0.15
α Boo	11.1	0.02–0.15
α Aur	14	0.04–0.05
α Tau	21	0.02–0.15
α Leo	22	0.02
		0·01†
α Eri	28	0.07
α Gru	29	0·09–0·18
		0·18†
HR 1099	33	0.003–0.007
η UMa	42	0.005
G191−B2B	47	>0.03
σ Sgr	57	<0.17
HZ 43	62	<0.013
α Pav	63	<0.1
β Cen	81	0.13
β Lib	83	0.06–0.13
ζ Cen	83	<0.39
α Vir	87	0.037
Feige 24	90	0.02–0.05
λ Sco	100	<0.078

Mean hydrogen column density within 100 pc = 1.8×10^{17} cm^{-2} pc^{-1}.
† Multiple entries denote independent measurements.
(Adapted from Cash, W., Bowyer, S. & Lampton, M., *Astron. Astrophys.*, **80**, 67, 1979.)

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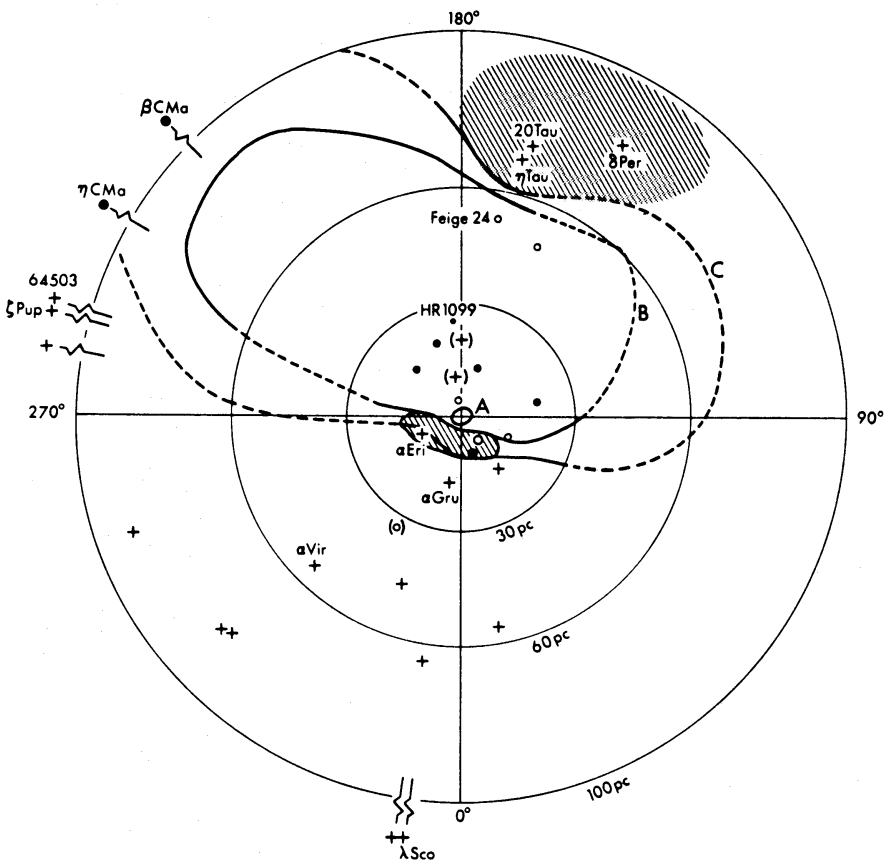
Neutral hydrogen column density

Neutral hydrogen column density N_{HI} contours projected onto the plane of the galaxy ($b = 0°$). The Sun is at the center of this plot, distances out to 100 pc are indicated, and the direction towards the galactic center ($l = 0°$) is at the bottom. Line A is the contour of $N_{HI} \sim 5 \times 10^{17}\,cm^{-2}$, corresponding to $\tau_{500\,Å} = 1$, $\tau_{200\,Å} \approx 0.1$, and $\tau_{100\,Å} \approx 0.01$. Line B is the contour of $N_{HI} = 25 \times 10^{17}\,cm^{-2}$, corresponding to $\tau_{500\,Å} = 5$, $\tau_{200\,Å} \approx 0.5$, and $\tau_{100\,Å} \approx 0.05$. Line C is the contour of $N_{HI} \sim 50 \times 10^{17}\,cm^{-2}$, corresponding to $\tau_{500\,Å} = 10$, $\tau_{200\,Å} \approx 1$, and $\tau_{100\,Å} \approx 0.1$. All open circles are white dwarfs. Small circles represent stars with $N_{HI} \leqslant 5 \times 10^{17}\,cm^{-2}$, medium circles represent stars with $5 \times 10^{17} < N_{HI} < 25 \times 10^{17}\,cm^{-2}$, the large circles represent stars with $25 \times 10^{17} < N_{HI} < 50 \times 10^{17}\,cm^{-2}$, and the crosses represent stars with $N_{HI} > 50 \times 10^{17}\,cm^{-2}$. Stars with measured hydrogen column densities but which are located within 10 pc projected distance are not plotted. (From *FUSE Science Working Group Report*, NASA, 1983.)



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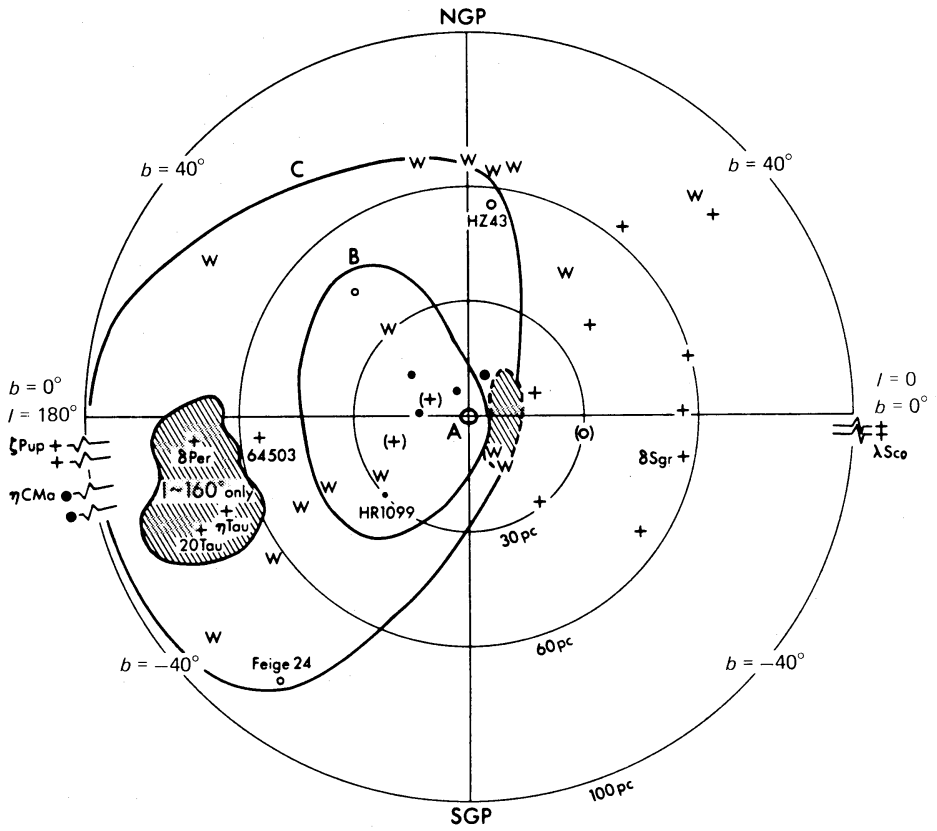
Neutral hydrogen column density (*cont.*)

Same as previous diagram but projected onto a plane intercepting the Galactic plane at Galactic longitudes $l = 0°$ and 180°, and passing through the North Galactic Pole (*top*) and South Galactic Pole (*bottom*). The symbols have the same meanings as before, and those stars with projected distances of less than 10 pc are generally not plotted. W symbols designate white dwarfs not yet observed. Many of these are within the cavity of low HI absorption and will be observable below 900 Å. (From *FUSE Science Working Group Report*, NASA, 1983.)



Bibliography

The Universe at Ultraviolet Wavelengths, NASA Conference Publication 2171, 1980.

Proceedings of the Fourth European IUE Conference, ESA SP-218, 1984.

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