Interstellar Grains

What roles do they play in the ISM?

(1) Extinction — absorption and scattering; λ-dependent
(2) Formation of molecules
(3) Cooling / heating of the ISM; energy exchange
(4) Absorption and re-emission; optical / UV / x-ray $\to$ IR.

extinction:

$$I_\lambda = I_{\lambda 0} e^{-\tau_\lambda}$$

I_λ: intensity at λ
τ_λ: optical depth at λ

To determine the extinction curve, we use a pair of stars with identical spectral type.

$$\frac{F_\lambda(1)}{F_\lambda(2)} = \frac{D_2^2}{D_1^2} e^{-[\tau_\lambda(1) - \tau_\lambda(2)]}$$

F_λ: observed flux

If D_1, D_2 are known, and $\tau_\lambda(2) \to 0$, then the ratio $F_\lambda(1)/F_\lambda(2)$ can be used to determine the extinction curve.

$$m = M + 5 \log d - 5 + A$$

m: apparent magnitude; M: absolute magnitude; d: distance in pc; A: extinction

$$\boxed{\frac{L_2}{L_1} = 100^{(M_1 - M_2)/5}}$$

$$\frac{\text{absorbed flux}}{\text{unabsorbed flux}} = 100^{-A_\lambda/5}$$

$$B = M_B + 5\log d - 5 + A_B$$
$$V = M_V + 5\log d - 5 + A_V$$

$$B-V = (M_B - M_V) + (A_B - A_V)$$

$$A_B - A_V = (B-V) - (M_B - M_V) \equiv E(B-V)$$ color excess

$$\frac{A_\lambda}{E(B-V)} = \frac{A_\lambda - A_V}{E(B-V)} + \frac{A_V}{E(B-V)} = \frac{E(\lambda - V)}{E(B-V)} + R$$

$$R \equiv \frac{A_V}{E(B-V)} \approx 3.1$$

Extinction curves are frequently plotted as

$$\frac{E(\lambda-V)}{E(B-V)} \quad \text{vs} \quad \frac{1}{\lambda}$$

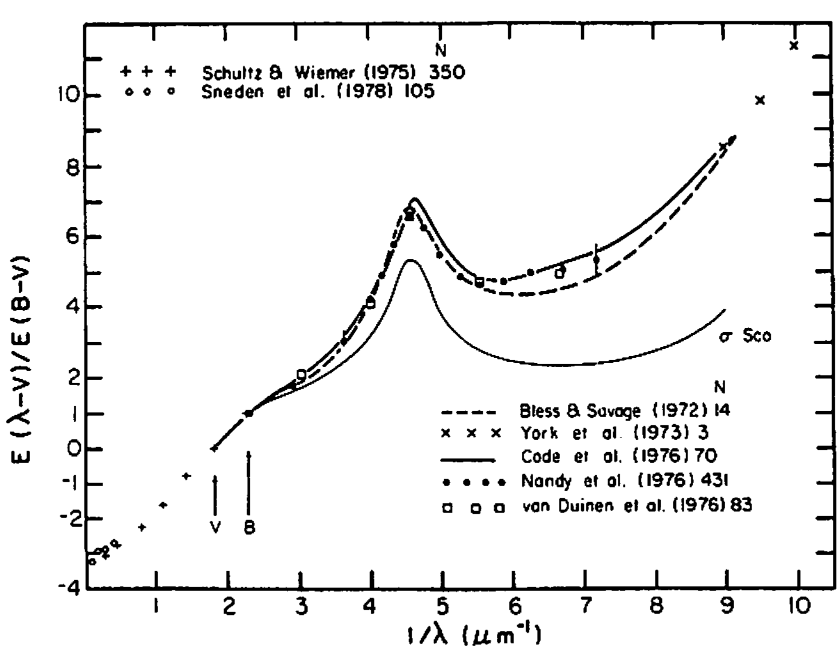
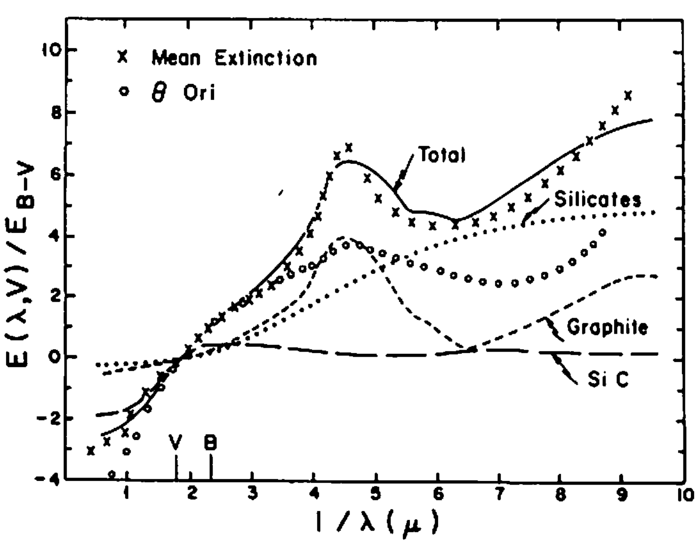


Table 2 An average interstellar extinction curve

	$\lambda(\mu m)$	$\lambda^{-1}(\mu m^{-1})$	$E(\lambda-V)/E(B-V)$	$A_\lambda/E(B-V)$
	∞	0	−3.10	0.00
L	3.4	0.29	−2.94	0.16
K	2.2	0.45	−2.72	0.38
J	1.25	0.80	−2.23	0.87
I	0.90	1.11	−1.60	1.50
R	0.70	1.43	−0.78	2.32
V	0.55	1.82	0	3.10
B	0.44	2.27	1.00	4.10
	0.40	2.50	1.30	4.40
	0.344	2.91	1.80	4.90
	0.274	3.65	3.10	6.20
	0.250	4.00	4.19	7.29
	0.240	4.17	4.90	8.00
	0.230	4.35	5.77	8.87
	0.219	4.57	6.57	9.67
	0.210	4.76	6.23	9.33
	0.200	5.00	5.52	8.62
	0.190	5.26	4.90	8.00
	0.180	5.56	4.65	7.75
	0.170	5.88	4.77	7.87
	0.160	6.25	5.02	8.12
	0.149	6.71	5.05	8.15
	0.139	7.18	5.39	8.49
	0.125	8.00	6.55	9.65
	0.118	8.50	7.45	10.55
	0.111	9.00	8.45	11.55
	0.105	9.50	9.80	12.90
	0.100	10.00	11.30	14.40

In the UV wavelength range, an extinction peak is present at ~2175 Å ("2200 Å bump").



UV: Small graphite grains

$\bar{a} = 2.5 \times 10^{-6}$ cm

Visual: SiC grains

$\bar{a} = 7.5 \times 10^{-6}$ cm

far UV: MgSi, AlSi

$\bar{a} = 4.5 \times 10^{-6}$ cm

Extinction curves differ toward different stars, depending on the dust compositions

At optical wavelengths, $\tau_\lambda = c\, f(\lambda)$,
where c is a constant factor.

Nebular spectroscopists lik to normalize line strengths to $I(H\beta)$, and let $f(H\beta) = 0$

$$\frac{I_\lambda}{I_{H\beta}} = \frac{I_{\lambda 0}}{I_{H\beta 0}}\, e^{-(\tau_\lambda - \tau_{H\beta})}$$

$$= \frac{I_{\lambda 0}}{I_{H\beta 0}}\, e^{-c[f(\lambda) - f(H\beta)]}$$

$$= \frac{I_{\lambda 0}}{I_{H\beta 0}}\, e^{-c f(\lambda)}$$

$$2.3\, c \equiv c(H\beta) = -\log \frac{I_{H\beta}}{I_{H\beta 0}} \qquad \frac{I_{H\beta}}{I_{H\beta 0}} = 10^{-c(H\beta)}$$

To determine $c(H\beta)$, use $H\alpha$ and $H\beta$ lines,
i.e. Balmer decrements.

$$\frac{I_{H\alpha}}{I_{H\beta}} = \frac{I_{H\alpha 0}}{I_{H\beta 0}}\, 10^{-c(H\beta)\, f(H\alpha)} \qquad f(H\alpha) = -0.308$$

$$= 2.86 \times 10^{0.308\, c(H\beta)}$$

$$c(H\beta) = \frac{1}{0.308} \log\left(\frac{I_{H\alpha}/I_{H\beta}}{2.86}\right)$$

With $I_{H\beta 0} \equiv 100$, $\quad I_{\lambda 0} = 100 \times \left(\frac{I_\lambda}{I_{H\beta}}\right) 10^{c(H\beta) f(\lambda)}$

$$A_V = 2.17\, c(H\beta)$$

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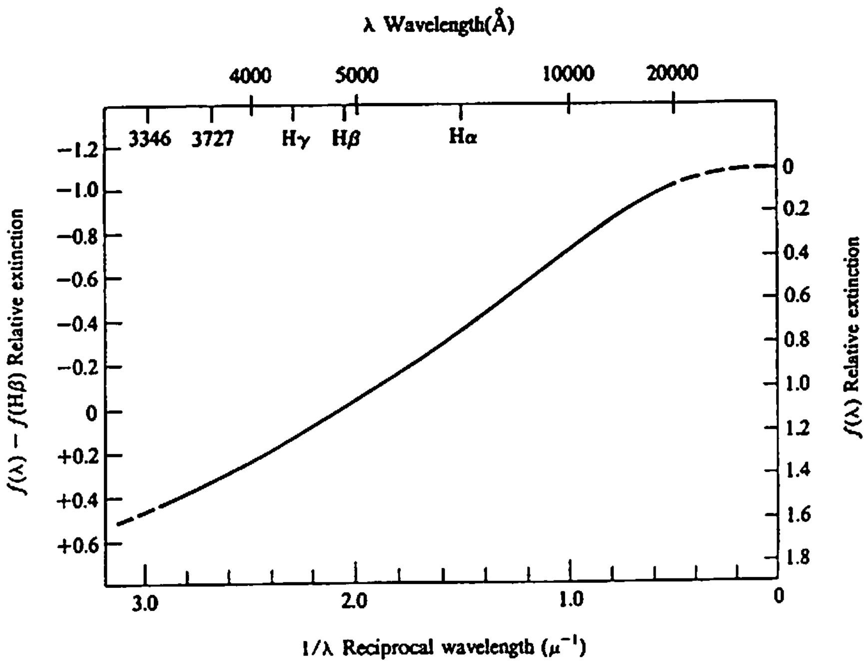

FIGURE 7.1
Standard interstellar extinction curve as a function of wavelength as described in text and listed in Table 7.1. Note that the left-hand scale gives extinction relative to extinction at Hβ; the right-hand scale shows total extinction and is chosen so that $\tau_\lambda \rightarrow 0$ as $\lambda \rightarrow \infty$.

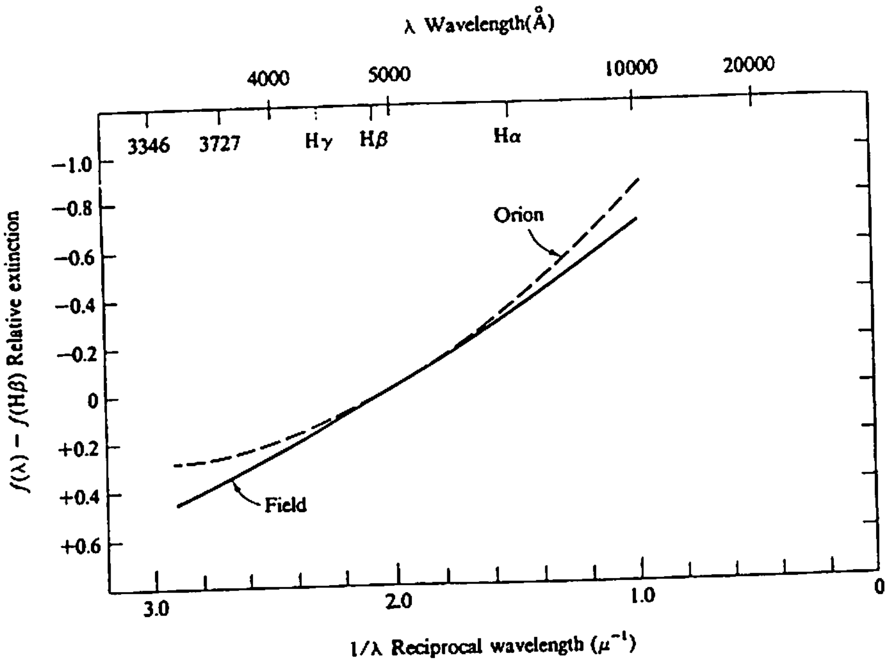

FIGURE 7.2
Average extinction for θ^1 Ori, the Trapezium stars, in NGC 1976, compared with average extinction for stars in Cygnus, Cepheus, Perseus and Monoceros.

λ (Å)	Ion	f
3727......	[O II]	0.278
3868......	[Ne III]	0.249
4026......	He I	0.210
4068......	[S II][b]	0.200
4102......	H I	0.193
4340......	H I	0.144
4363......	[O III]	0.140
4472......	He I	0.110
4741......	[Ar IV]	0.034
4861......	H I	0.000
4959......	[O III]	−0.025
5007......	[O III]	−0.037
5518......	[Cl III]	−0.147
5538......	[Cl III]	−0.147
5755......	[N II]	−0.189
5876......	He I	−0.209
6300......	[O I]	−0.273
6311......	[S III]	−0.274
6563......	H I	−0.308
6584......	[N II]	−0.310
6678......	He I	−0.322
6717......	[S II]	−0.326
6731......	[S II]	−0.328
7065......	He I	−0.369
7136......	[Ar III]	−0.380
$C(H\beta)$..............................		
$\log S(H\beta)$[c]		