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Determining the extinction through dark clouds

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Abstract. We discuss the problem of a consistent determination of the visual extinction to objects in and behind a dark cloud. The use of near-infrared colours is discussed, in particular the H-K colours. We concentrate on the uncertainties, with emphasis on the extinction law and on the intrinsic colours of the young stars embedded in a dark cloud. The cases of the two intensively studied nearby star-forming clouds, Taurus and Ophiuchus, are addressed.

Key words: ISM: clouds – ISM: dust, extinction – infrared: ISM: lines and bands

1. Determining the visual extinction

Extinction is produced by the dust in the line-of-sight to an object and the column density of dust in a given line of sight is often expressed in terms of the extinction, A_v, that it would produce in the photometric V band, at 0.55 μm. Unfortunately, A_v is not always a directly measurable quantity, for example if an object is undetectable at V due to high A_v, or if the true spectrum of the extinguished object is unknown. Determination of A_v, and hence dust column densities, may involve extrapolation from the extinction at some other wavelength which is dependent on knowing the dust extinction law (Rieke & Lebofsky 1985, Whittet et al. 1996).

For objects with a known spectral type, determination of A_v is relatively straightforward because the intrinsic colours of the object will be known. Determination of A_v then depends only on the assumed interstellar or dark cloud extinction law. For embedded young stars, often optically invisible and/or with unknown spectral type, the determination of A_v becomes very difficult. Methods used range from near-infrared colours (e.g. Elias 1978a,b, Tanaka et al. 1990, Greene & Meyer 1995, Whittet et al. 1996), to multiwavelength fits of the near-infrared range of the SED of the object (Myers et al. 1987, Strom et al. 1989, Heyer et al. 1990), from the use of the observed optical depth of the silicate feature (e.g. Lacy et al. 1984, Whittet et al. 1996), to the use of the estimated optical depth at 800 μm (Barsony & Kenyon 1992), from fits of the entire SED of the object (Ladd et al. 1991), to the use of abundances of molecules derived from radio molecular line observations (Wilking & Lada 1983, Liseau et al. 1995). Each method has problems, and visual extinctions determined by different methods do not always agree (cf. Wilking & Lada 1983, Gürtler et al. 1991, Hanner et al. 1995). The requirements of each method imply that they cannot all be used for all the objects observed toward a dark cloud. To determine the extinction to a sample of objects in and behind a dark cloud in a consistent way, it is thus necessary to select a single method which can be applied to all such objects, and for which the associated problems and sources of uncertainties may be most easily overcome.

2. The use of near-infrared colours

The common use of near-infrared (henceforth NIR) colours has the advantage that it can be applied to both background and embedded objects, and the information needed for its use – the near-infrared magnitudes – is generally available for the objects of interest.

The determination of A_v from NIR colours can be made from: J-H (e.g. Strom et al. 1995, Casanova et al. 1995), J-K (e.g. Elias 1978a,b, Smith et al. 1993, Kenyon & Hartmann 1995), H-K (e.g. Wilking & Lada 1983, Tanaka et al. 1990, Eiroa & Casali 1992, Lada et al. 1994, Casanova et al. 1995, Greene & Meyer 1995, Whittet et al. 1996), or K-L (Casali 1991). The choice depends on two conditions: the existence of appropriate magnitude measurements, and on a compromise between scattering effects and infrared excess. In the case of the background field stars, these conditions pose no problem, since the field stars have been observed in all those bands, and they do not "suffer" from infrared excess[1]. For the young stars embedded in the clouds, however, these conditions pose severe problems. First, because of large extinction, deeply embedded objects are often only detected at wavelengths longer than J. If the same criterion for the determination of A_v is to be applied to all objects in a cloud for easier comparison of the results, that immediately rules out the use of J-H and J-K. Another problem is the presence of disks around the embedded young stars, which emit at infrared wavelengths causing a near-infrared excess. The contribution from the thermal emission of the heated dust in the disk

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[1] Only late-type stars surrounded by dust (e.g. Mira variables and carbon stars), typically with spectral type later than M5 and with luminosity class I, II and possibly III, show infrared excess due to the presence of the circumstellar dust (cf. Bessell & Brett 1988).

starts being noticeable around the K band (2.2 μm; Casanova et al. 1995), where it dominates the flux from the YSO (cf. Kenyon et al. 1993a, Skrutskie et al. 1996). However, as shown by Kenyon & Hartmann (1995), the fraction of excess emission is larger at L. One other problem is the scattering of radiation *into* the beam by the dust grains, which mostly affects data at optical wavelengths but which is still felt at NIR wavelengths. Light scattered into the beam is a problem because extinction only accounts for absorption of radiation and scattering of radiation *out* of the beam along the line-of-sight. However, as the scattering efficiencies decrease with increasing wavelength, the K band is less affected by scattered light than the J band, although even at K a fraction of the emergent flux is still scattered radiation (Heyer et al. 1990, Kenyon et al. 1993b). As shown by Kenyon et al. (1993b), the amount of scattered light from a given source collected in a given telescope beam, depends not only on the wavelength being observed, but on the inclination angle of the object relative to the observer (or, in general, on the local geometry of the source), and on the beam size. While the NIR colours do not show a monotonic behaviour with the inclination angle, they become bluer with increasing aperture size because more blue scattered light goes into a larger beam.

The best choice for a consistent determination of the visual extinction to a sample of objects in and behind a dark cloud is thus the use of the H-K colours. However, near-infrared imaging observations of embedded Young Stellar Objects (YSOs) have shown that, at these wavelengths, even the very deeply embedded objects are not point sources but are often surrounded by extended cometary shaped nebulosities (e.g. Heyer et al. 1990). Polarization measurements have led to the identification of such nebulosities as scattered light, possibly from a cavity carved by energetic stellar winds associated with the forming stars (e.g. Moore & Emerson 1992, Emerson & Moore 1996, Whitney et al. 1997). Then visual extinctions determined from NIR colours will be an underestimate of the true visual extinction to the source. The problem can be minimized by avoiding the shortest wavelengths but, in any case, the result may underestimate $\mathrm{A_v}$ by a factor of ~ 2. Independently of the method chosen to estimate $\mathrm{A_v}$, is extremely difficult to determine the *true* extinction to an object embedded in a dark cloud (Strom et al. 1995). Applying the same method to all the objects observed toward a dark cloud implies that they should all be affected by the same problems in roughly the same way. The differences in circumstances between background field stars and embedded objects should be taken into account when interpreting observations.

2.1. Estimating $\mathrm{A_v}$ *from E(H-K)*

The determination of the visual extinction from NIR colours, requires knowledge of the extinction law.

The visual extinction to an object, $\mathrm{A_v}$, can be determined from the H-K colour excess of the object E(H-K), using:

$$\mathrm{A_v} = k\,\mathrm{E(H-K)} = k\,[\mathrm{(H-K) - (H-K)_o}] \tag{1}$$

where k is the proportionality factor characteristic of the extinction law, H and K are the apparent magnitudes of the object at H (1.65 μm) and K (2.2 μm) respectively, (H-K) is the observed colour of the object, and (H-K)$_\mathrm{o}$ is the intrinsic colour of the object.

To estimate $k(\equiv A_V/E(H-K))$, the definitions of colour excess and extinction at a given wavelength can be used to notice that:

$$\frac{\mathrm{A_v}}{\mathrm{E(H-K)}} = \frac{\dfrac{\mathrm{A_v}}{\mathrm{A_{\lambda_{ref}}}}}{\gamma_1 - \gamma_2} \tag{2}$$

where $\gamma_1 = \mathrm{A_H/A_{\lambda_{ref}}}$ and $\gamma_2 = \mathrm{A_K/A_{\lambda_{ref}}}$, and $\mathrm{A_{\lambda_{ref}}}$, $\mathrm{A_H}$, and $\mathrm{A_K}$ correspond to the extinction at the λref, H, and K bands, respectively. λ_ref can be any wavelength, but here we will take λ_ref as the J (1.25 μm) band for reasons that will be explained in the following section.

2.1.1. The extinction law

$\mathrm{A_\lambda/A_v}$, known as the “extinction law”, is not the same in all lines-of-sight and is characterized by the optical total-to-selective extinction ratio, $\mathrm{R_v \equiv A_v/E(B-V)}$. $\mathrm{R_v}$ depends on the environment of the extinguishing dust in the line-of-sight, since it is dependent on the composition and/or size of the grains (Emerson 1988, Smith et al. 1993). While the shape of the extinction law is observed to be markedly different for different lines-of-sight (i.e. different values of $\mathrm{R_v}$) at optical and ultraviolet wavelengths, *at NIR wavelengths* the law is constant over all lines-of-sight, and therefore independent of $\mathrm{R_v}$ (e.g. Landini et al. 1984), as is clear if the extinction law is defined with reference to the extinction at one of the NIR photometric bands, such as J, rather than at V (Mathis 1990). The “universal” character of the extinction law at NIR wavelengths is shown in the fact that, within the observational uncertainties, the ratio $\mathrm{A_\lambda/A_J}$ for $\lambda \geq 0.90\,\mu$m appears to be independent of direction and therefore of $\mathrm{R_v}$ (Cardelli et al. 1989, Martin & Whittet 1990, Mathis 1990). For this reason, $(\gamma_1 - \gamma_2)$ in Eq. (2) is independent of $\mathrm{R_v}$. Setting λ_ref to J and using the estimated extinction law tabulated in Mathis (1990, their Table 1): $(\gamma_1 - \gamma_2) = 0.242$. Then, $\mathrm{A_v/E(H-K)}$ is dependent only on the ratio $\mathrm{A_v/A_J}$. This ratio, given also in Mathis (1990) for two values of $\mathrm{R_v}$ (3.1 and 5.0), can be estimated for any value of $\mathrm{R_v}$ using the fit to NIR and optical data obtained by Cardelli et al. (1989) and adopted by Mathis (1990).

Lines-of-sight towards stars obscured by dust in the diffuse ISM are generally characterized by values of $\mathrm{R_v} \sim 3.1$, while lines-of-sight through dense clouds usually have values of $\mathrm{R_v} \geq 4$ (Mathis 1990). In the case of the two most well-known nearby star-forming clouds, Ophiuchus appears to be characterized by $\mathrm{R_v} \simeq 4.2$, while in Taurus $\mathrm{R_v} \simeq 3.0$–3.5 (Martin & Whittet 1990 and references therein). Smith et al. (1993) point out that the lines-of-sight in Taurus seem to be differentiated in the sense that the lines-of-sight where ice mantles in dust grains are present show values of $\mathrm{R_v} \sim 3.5$–3.7, while those where ices seem to be absent show values of $\mathrm{R_v} \sim 2.8$–2.9, as expected when there are ice mantles on the grains.

Taking the fit by Cardelli et al. (1989) to determine $\mathrm{A_v/A_J}$, the following estimates of $\mathrm{A_v/E(H-K)}$ are obtained for the relevant values of $\mathrm{R_v}$:

$$\begin{cases} \mathrm{R_v} = 3.1 \Longrightarrow & \mathrm{A_v/E(H-K)} = 14.6 \\ \mathrm{R_v} = 3.8 \Longrightarrow & \mathrm{A_v/E(H-K)} = 13.6 \\ \mathrm{R_v} = 4.2 \Longrightarrow & \mathrm{A_v/E(H-K)} = 13.2 \end{cases} \tag{3}$$

These values can be compared with those derived by Whittet et al. (1996): $\mathrm{A_v/E(H-K)} \simeq 16.1$ for the diffuse ISM and $\mathrm{A_v/E(H-K)} \simeq 12.9$ for Ophiuchus. Because $\mathrm{A_v/E(H-K)}$ results from a division by the difference of two numbers of comparable magnitude, the result will be affected by an uncertainty associated with the fluctuations of those two numbers (γ_1 and γ_2). For that reason, despite the fact that the extinction law in the infrared appears to be universal and that therefore γ_1 and γ_2 should be independent of the direction, the uncertainties associated with the observations, or even real variations of the infrared extinction law below the current limit of detection cause $\gamma_1 - \gamma_2$ to fluctuate leading to different values of $\mathrm{A_v/E(H-K)}$ for the same $\mathrm{R_v}$. However, such variations only amount to uncertainties of at most 10% on the derived values of $\mathrm{A_v}$.

2.1.2. The intrinsic colours (H-K)$_\mathrm{o}$

(H-K)$_\mathrm{o}$ is readily found for those objects for which a determination of the spectral type is possible and which do not show an infrared excess (namely the field stars). For the YSOs it is not possible to determine the spectral type of the underlying object due to the large extinction which often completely obscures the object at optical and NIR wavelengths, and because the accretion disks surrounding the embedded young stars contribute with significant infrared excesses, causing the central star+disk systems to have intrinsic colours that are redder than the intrinsic colour of the forming young star alone. Moreover, the strongly anisotropic distributions of material around YSOs (in the form of disks and spherically asymmetric envelopes) also result on a dependence of the colour of the object with the unknown viewing angle.

Observationally, embedded YSOs associated with a dark cloud can be classified[2] as Class 0, I, II, or III objects. Class 0 objects are detectable only at far-infrared and submillimiter wavelengths and will thus not be discussed further.

Class I objects are thought to consist of a central star+disk system surrounded by a thick dusty envelope that completely obscures the central system. Such objects are thought to be the precursors of the more evolved Class II objects (Classical T-Tauri stars, hereafter CTTSs, fall into this category) (e.g. Adams et al. 1987). The assumption is made that the central objects of Class I sources are similar to Class II objects. As noted by Greene & Meyer (1995), YSOs with significant infrared excesses (caused by the emission of warm dust grains near the central star) should be dereddened to the colours of the T-Tauri stars, since their extinctions would be artificially increased if they were instead dereddened to the intrinsic photospheric colours of their (estimated) spectral types. Unfortunately this cannot be done without further problems because CTTSs have a wide range of intrinsic (H-K) colours: from ~ 0.2 to ~ 1.6 (e.g. Strom et al. 1993). However, Greene et al. (1994) have noticed that most CTTSs (without large IR excesses) have intrinsic colours within a smaller interval ($0.2 < \mathrm{H-K} < 0.8$) and can be represented by the mean value $\mathrm{(H-K)_o} = 0.5$. This is also in agreement with the value derived by Eiroa & Casali (1992) from the Cohen & Kuhi (1979) sample in Taurus and Orion.

Class III objects are young stars which have almost completely dissipated their surrounding disk and envelope and are approaching the main-sequence. Their estimated average intrinsic (H-K) colour is 0.1 (Casanova et al. 1995[3], Greene & Meyer 1995). In colour-colour diagrams, the Class III sources (weak-line T-Tauri stars would fall into this category) are located in the region expected for normal, slightly reddened stars (Strom et al. 1993), without infrared excesses. The spectral types of most of them have been determined and so their intrinsic colours are known to a much better accuracy than their precursors Class I and II sources.

2.2. Estimating $\mathrm{A_v}$ *from E(J-K)*

In the cases where H-K colours are not available in the literature, it is possible to determine $\mathrm{A_v}$ from available J-K colours. The relation between $\mathrm{A_v}$ and E(J-K) is:

$$\mathrm{A_v} = \frac{\frac{\mathrm{A_v}}{\mathrm{A_J}}}{1-\gamma_2}\,\mathrm{E(J-K)} \tag{4}$$

where γ_2 has the same meaning as previously defined, and the values of $\mathrm{A_v/A_J}$ and γ_2 can be obtained as explained in the previous section. The proportionality factor between $\mathrm{A_v}$ and E(J-K) is now:

$$\begin{cases} \mathrm{R_v} = 3.1 \Longrightarrow & \mathrm{A_v/E(J-K)} = 5.74 \\ \mathrm{R_v} = 3.8 \Longrightarrow & \mathrm{A_v/E(J-K)} = 5.32 \\ \mathrm{R_v} = 4.2 \Longrightarrow & \mathrm{A_v/E(J-K)} = 5.17 \end{cases} \tag{5}$$

3. The extinction through Taurus and Ophiuchus

As an application of the method previously discussed, the cases of Taurus and Ophiuchus will now be addressed. The sample of objects is presented in Table 1, along with the information relevant for the calculation of $\mathrm{A_v}$. The choice of objects in the sample is discussed in a companion paper (Teixeira & Emerson 1999). The sources' approximate coordinates are given in column 2 and 3, the spectral class (in the case of YSOs) or spectral type (in the case of field stars) in column 4, the observed H-K colours in column 6, the $\mathrm{A_v/E(H-K)}$ ratio in column 8,

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[2] The spectral classification scheme of YSOs can be found in, e.g., Lada (1987) and André & Montmerle (1994).

[3] In their paper, Casanova et al. (1995) quote a value (H-K)$_o$ = -0.1, where the negative sign is probably a typographical mistake, since the value actually used in the expression of A_K was +0.1, consistent with the data presented in the reference they cite, Strom et al. (1993).

Table 1. Visual extinction, A_v towards embedded YSOs and field stars in and behind the Taurus and Ophiuchus molecular clouds. The meaning and uncertainties of the remaining symbols is discussed in the text.

Object	$\alpha(2000)^{a}$	$\delta(2000)^{a}$	Sp.class/type	Ref.^{h}	$(H-K)$	Ref.^{h}	$A_V/E(H-K)$	$(H-K)_o$	A_V
Taurus, YSOs									
Elias 1	04 18 40.7	+28 19 16	Class II	7	1.27	1	13.6	0.5	10.5
Elias 7	04 29 23.8	+24 33 02	Class I	8	1.34	8	13.6	0.5	11.4
Elias 18	04 39 55.7	+25 45 02	Class II	7	1.93	12	13.6	0.5	19.4
Elias 23	04 32 15.4	+24 29 00	Class I/II	7	1.20	11	13.6	0.5	9.5
HL Tau	04 31 38.4	+18 14 00	Class I/II	9	1.61	13	13.6	0.5	15.1
L1489	04 04 43.1	+26 18 58	Class I	7	2.42	14	13.6	0.5	26.1
L1524	04 26 56.4	+24 43 36	Class I	7	2.48	14	13.6	0.5	26.9
L1536S	04 33 19.1	+22 46 33	Class II	7	1.61	11	13.6	0.5	15.1
L1551 IRS5	04 31 33.9	+18 08 08	Class I	7	1.54	12	13.6	0.5	14.1
L1551NE	04 31 43.5	+18 06 31	Class I	7	2.14	12	13.6	0.5	22.3
TMC1A	04 39 35.0	+25 41 47	Class I	7	2.85	14	13.6	0.5	32.0
Taurus, field stars									
Elias 3	04 23 24.6	+25 00 09	K2III, K4III	1, 2	0.75	1	13.6	0.13	8.4
Elias 6	04 29 07.7	+24 43 50	M8III, M7III	1, 2	0.84	1	13.6	0.37	6.4
Elias 9	04 32 11.5	+24 33 38	M4III	1	0.57	1	13.6	0.245	4.4
Elias 13	04 33 25.9	+26 15 34	K2III	1	0.97	1	13.6	0.115	11.6
Elias 14	04 38 58.3	+26 31 07	M5III	1	0.71	1	13.6	0.285	5.8
Elias 15	04 39 26.8	+25 52 59	M2III	1	1.32	1	13.6	0.215	15.0
Elias 16	04 39 38.7	+26 11 25	K1III, K2III	1, 2	1.84	1	13.6	0.11	23.5
Elias 17	04 23 24.6	+25 00 09	M5III	1	0.61	1	14.6	0.285	4.7
HD28975	04 34 50.0	+24 14 40	A3(V)	3, 2	0.11	3	14.6	0.008	1.5
HD29647	04 41 08.0	+25 59 32	B7IV	2	0.21	3	13.6	0	2.9
HD283701	04 34 54.9	+27 12 12	A0V	4	0.08	4	14.6	0	1.2
HD283809	04 41 24.9	+25 54 48	B3V	2	1.0^{c}	2	**g1**	**c**	5.3^{g1}
HD283812	04 44 24.8	+25 31 44	A2V	4	0.13	4	14.6	0.005	1.8
Tamura 2	04 37 28.3	+26 10 25	M2III	2	2.2^{d}	15	**g1**	1.08^{e}	6.0^{g1}
Tamura 8	04 40 58.1	+25 54 16	K5III	5	5.0^{d}	15	**g1**	0.95^{e}	21.5^{g1}
Tamura 12	04 41 02.8	+25 39 55	*n.i.*^{b}		2.1^{d}	15	**g2**	1.0^{f1}	6.3^{g2}
Tamura 16	04 42 35.6	+25 27 13	*n.i.*^{b}		2.0^{d}	15	**g2**	1.0^{f1}	5.7^{g2}
Tamura 17	04 44 01.5	+25 20 13	M8III	2	2.0^{d}	15	**g2**	1.27^{e}	4.2^{g2}
Ophiuchus, YSOs									
Elias 21	16 26 21.3	-24 23 02	Class I	10	2.45	6	13.2	0.5	25.7
Elias 23	16 26 24.1	-24 24 48	Class II	10	1.76	16	13.6	0.5	17.1
Elias 24	16 26 24.2	-24 16 13	Class II	10	1.44	17	13.6	0.5	12.8
Elias 25	16 26 34.2	-24 23 27	Class III	10	0.64	16	13.6	0.1	7.3
Elias 27	16 26 44.7	-24 23 07	Class II	10	1.78	6	13.6	0.5	17.4
Elias 29	16 27 09.5	-24 37 21	Class I	10	4.12	16	13.2	0.5	47.8
Elias 30	16 27 10.3	-24 19 12	Class II	10	0.72	6	13.6	0.5	3.0
Elias 32	16 27 28.5	-24 27 17	Class II	10	1.94	16	13.2	0.5	19.0
Elias 33	16 27 30.4	-24 27 34	Class II	10	2.23	16	13.2	0.5	22.8
WL5	16 27 18.0	-24 28 52	Class III	10	4.14	16	13.2	0.1	53.3
WL6	16 27 21.4	-24 29 48	Class I	10	4.39	16	13.2	0.5	51.3
WL12	16 26 44.2	-24 34 47	Class I	10	3.28	16	13.2	0.5	36.7
WL16	16 27 02.1	-24 37 26	Class II?	10	2.44	16	13.2	0.5	25.6

Table 1. (continued)

Object	$\alpha(2000)^{a}$	$\delta(2000)^{a}$	Sp.class/type	Ref.[h]	$(H-K)$	Ref.[h]	$A_V/E(H-K)$	$(H-K)_o$	A_V
Ophiuchus, field stars									
Elias 15	16 26 05.8	-24 42 54	M6III	6	1.08	6	13.6	0.30	10.6
Elias 35	16 27 46.7	-24 23 22	K6III	6	1.05	6	14.6	0.165	12.9
Elias 44	16 33 02.6	-24 22 41	M4III	6	0.82	6	13.6	0.245	7.8
Elias 47	16 38 54.8	-24 11 20	*n.i.*[b]		0.91	6	13.6	0.2[f2]	9.7

[a] Coordinates from Gezari et al. 1997.

[b] *n.i.*: not identified.

[c] No H-K colour available, only E(J-K) found in the literature.

[d] No H-K colour available, only J-K colour found in the literature.

[e] (J-K)$_o$

[f1] Average (J-K)$_o$ and [f2] average (H-K)$_o$, assuming sources are background late-type giants.

[g1] $A_V = 5.32\,E(J-K)$. [g2] $A_V = 5.74\,E(J-K)$. See text for details.

[h] *References:* 1. Elias 1978a; 2. Smith et al. 1993; 3. Vrba & Rydgren 1985; 4. Straizys et al. 1982; 5. Whittet et al. 1988; 6. Elias 1978b; 7. André & Montmerle 1994; 8. Leinert & Haas 1989; 9. Stapelfeldt et al. 1995; 10. Kenyon & Hartmann 1995; 11. Myers et al. 1987; 12. Whitney et al. 1997; 13. Molinari et al. 1993; 14. Kenyon et al. 1993b; 15. Tamura et al. 1987; 16. Greene & Young 1992; 17. Greene et al. 1994.

the intrinsic (H-K) colours ($(\mathrm{H-K})_o$) in column 9, and the calculated visual extinction in column 10.

Where possible, the observed H-K colours were chosen from measurements with the same beam or aperture size; the smallest beam or aperture size that was common to most of the observations was $\sim 8''$. The intrinsic (H-K)$_o$ colours were assumed to be 0.5, 0.5, and 0.1 for Class I, II, and III objects, respectively. For the field stars with identified spectral types the intrinsic colours were taken from Koornneef (1983) and Bessell & Brett (1988). The ratio $\mathrm{A_v/E(H-K)}$ was taken to be that corresponding to $\mathrm{R_v} = 3.8$ for the objects in or behind Taurus with detections of H_2O and/or CO ices (cf. Teixeira & Emerson 1999). For objects in or behind Ophiuchus, $\mathrm{A_v/E(H-K)}$ was chosen to be that corresponding to $\mathrm{R_v} = 4.2$ for the lines-of-sight where *both* ices have been detected or where there is a significant detection of H_2O-ice ($\geq 5 \times 10^{17}\,\mathrm{cm}^{-2}$) but no detection of CO-ice; for the lines-of-sight where no CO-ice has been detected and with a small column density of H_2O-ice ($< 5 \times 10^{17}\,\mathrm{cm}^{-2}$), $\mathrm{A_v/E(H-K)}$ was chosen to be that corresponding to a smaller value of $\mathrm{R_v} = 3.8$. For the lines-of-sight through both clouds where *none* of the ices has been detected, $\mathrm{R_v}$ was assumed to be the same as the typical diffuse ISM value, and the corresponding value of $\mathrm{A_v/E(H-K)}$ was taken.

It must be stressed that the estimates of the visual extinction presented in Table 1 have a large degree of uncertainty, both in absolute value and in relative terms. The limitations to the determination of the absolute value of the visual extinction might render $\mathrm{A_v}$ inaccurate to a factor of 2. Such limitations come mainly from the uncertainty in $\mathrm{R_v}$ for each line-of-sight, from the uncertainties in the observed magnitudes, and from the uncertainty in the intrinsic colour of each object. The uncertainty in $\mathrm{A_v/E(H-K)}$ is likely to be, at worse, $\sim$10% but possibly typically smaller than 5%. The problems with the determination of H-K and (H-K)$_o$ are much more severe and are actually the determining factors in the accuracy to which $\mathrm{A_v}$ can be estimated with this method. When comparing measurements of H-K by different observers or even by the same observer but at different epochs or with different instruments, often variations as large as 0.3 mag can be found (compare, for example, the observations by Elias 1978b, Greene & Young 1992 and Strom et al. 1995). As for the intrinsic colours of the objects, the uncertainties can be very large for the embedded YSOs, possibly as large as 0.5 mag. Even if it is assumed that the estimates of the three parameters going into the determination of $\mathrm{A_v}$ ($\mathrm{A_v/E(H-K)}$, H-K, and (H-K)$_o$) are independent, the typical uncertainty in $\mathrm{A_v}$ for each object is still as large as 30%.

4. Summary

Despite all the difficulties and uncertainties, the use of H-K colours provides the best method for a consistent determination of the visual extinction to objects in and behind a dark cloud. Even though such a method may not provide a correct determination of the true $\mathrm{A_v}$, it allows comparative studies to be carried out without different points being affected by systematics of different methods. Nevertheless, each line-of-sight requires some knowledge of the extinction law, which might be estimated from other observations (e.g., ice mantles). Care should also be taken when comparing field stars and embedded YSOs, due to our poor knowledge of the intrinsic characteristics of the embedded young stars.

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