

A NEW LOOK AT THE DUST TOWARD OMICRON PERSEI AND SIGMA SCORPII WITH THE *INTERNATIONAL ULTRAVIOLET EXPLORER*

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ABSTRACT

The first *International Ultraviolet Explorer* (*IUE*) low dispersion spectra for σ Per and σ Sco have recently been obtained and extinction curves from 1150 to 3250 Å are presented. Our *IUE* data are compared with earlier studies using *OAO*, *Copernicus*, and *ANS* satellite data. The extinction toward σ Per has not been previously measured from 1850 to 3200 Å. The interstellar medium along these lines of sight has been extensively studied so it is of interest to consider the σ Sco and σ Per dust in the context of the average extinction law of Cardelli *et al.* [ApJ, 345, 245 (1989), hereafter referred to as CCM] which depends on one parameter, chosen to be R_v , the ratio of total-to-selective extinction. Apparently σ Per lies behind the edge of a dark cloud, while σ Sco lies within a H II region near a dark cloud. The σ Per dust shows a broad bump shifted to shorter wavelengths similar to other dark cloud lines of sight but shows no deviation from the CCM average curve in the far ultraviolet. The σ Sco dust does show a marked deviation from the CCM average law in the far ultraviolet. Although large, these deviations are more typical of dark cloud or diffuse sight lines rather than bright nebula sight lines. The σ Sco and σ Per UV extinction curves are not anomalous, nor are they prototypes for other lines of sight. The observed characteristics for the σ Sco and σ Per dust are examples of a continuum of characteristics observed along various sight lines depending on the local dust environments.

1. INTRODUCTION

The stars, σ Sco and σ Per, are among the brightest stars in the sky which lie behind a significant amount of interstellar matter. Therefore, it is not surprising that they have been the subject of many studies of the interstellar medium and were among the first lines of sight for which UV extinction curves were obtained (Stecher 1965). Herein lies the importance of these lines of sight in the study of the interstellar medium. Because few lines of sight are well studied, those few which are studied become prototypes and stereotypes for all other lines of sight. Therefore, it is very important to understand how prototypical or stereotypical these well-known sight lines are, and how the general properties of the ISM vary from one line of sight or environment to another. Linking observed parameters of interstellar dust, such as the wavelength dependence of the UV extinction, to the environment in which the dust exists, is of great importance to understanding the formation and evolution of dust. The few well-studied lines of sight like σ Per and σ Sco where we have some idea of abundances, depletions, densities, and temperatures take on greater significance.

Stecher (1965) used σ Sco and σ Per along with three other reddened stars to construct an average UV extinction curve which clearly showed the 2175 Å bump for the first time. Bless and Savage (1972) published the UV extinction curve of σ Sco alone, showing the far-ultraviolet [(FUV); defined here as 1100–1500 Å] extinction to be much flatter than “normal.” Since that time, the σ Sco extinction curve has been an often used example of “anomalous” extinction (e.g., Savage & Mathis 1979; Snow 1992). An average

interstellar extinction law [normalized to $E(B-V)$] was determined by combining several lines of sight (Seaton 1979; Savage & Mathis 1979). Some sight lines differ significantly from this average law. As mentioned above, σ Sco shows very flat FUV extinction. Other lines of sight such as ζ Oph show very steep FUV extinction. It is natural to infer that the dust properties and environments are different in clouds with differing FUV extinction slopes. The σ Sco and ζ Oph sight lines became the prototypes for these two types of anomalous extinction curves. While the extinction for σ Per was not known longward of 1800 Å, it has generally been considered a “ ζ Oph”-type cloud because of its steep FUV extinction (Snow 1976). These two “types” of clouds have been studied to look for other characteristics which differentiate their dust environments and might lead to the variations seen in extinction behavior.

Even with their small sample of stars, Bless & Savage (1972) noted an apparent relationship between low FUV extinction and large R_v , the ratio of total-to-selective extinction. This observed tendency was evidence that there is an average extinction law, $A(\lambda)/A(V)$, over the wavelength range 3.5–0.125 μ m, which is applicable to a wide range of interstellar dust environments in the UV [Cardelli *et al.* 1988; 1989, hereafter referred to as CCM; Cardelli & Clayton 1991, hereafter referred to as CC; Mathis & Cardelli 1992, hereafter referred to as MC]. This includes lines of sight through diffuse dust, dark cloud (DC) dust, and dust associated with star formation [bright nebula (BN)]. This mean extinction law depends on only one parameter which was chosen to be $R_v [= A(V)/E(B-V)]$. The existence of this law, valid over a large wavelength interval, suggests that the environmental processes which

modify the grains are efficient and affect all grains. When changes in the grain-size distribution which are reflected in the FUV extinction occur due to coagulation, the entire size distribution apparently varies in a systematic way. The σ Sco- and ζ Oph-type sight lines can be understood as the extremes of a continuum characterized by a range of R_v values from large to small. While there is some tendency for dust in DC to have higher values of R_v than diffuse sight lines, DC and BN sight lines display a wide range of R_v values. However, dust in most environments amenable to UV observations adheres to the CCM relationship. Where differences, due to the different environmental conditions along these various sight-line types, can be seen is in deviations from the CCM relation. CC and MC found that the scatter around the CCM relation is larger than can be expected from random errors. They find that sight lines through BN and DC show significant but different deviations from CCM which may result from the presence or absence of coatings on grains.

The CCM investigation was made easier through the parametrization of the UV extinction curve by Fitzpatrick & Massa (1986, 1988, 1990, hereafter referred to as FM). Although the UV extinction of σ Sco and σ Per has been studied with *OAO* and *Copernicus* (the UV extinction longward of 1800 Å has not been previously studied for σ Per with any instrument), these sight lines have not been investigated in the context of CCM and FM. Also, a much better job of spectral typing and selecting unreddened standards can be done using the large number of stars available in the *IUE* archive. This is very important for σ Sco and σ Per because both stars are spectroscopic binaries. To best accomplish this, low dispersion spectra suitable for constructing UV extinction curves have been obtained with *IUE* for both of these stars.

2. NEW DATA

New low dispersion LWP and SWP spectra were obtained with *IUE* on 1992 September 4. Because the stars are so bright in the UV, the shortest possible exposures with the *IUE* were obtained. The exposure time is controlled by the on-board computer (OBC). Thus, the exposure time is quantized by an OBC "tick," which is 0.41 s. For exposure times of only one or a few OBC ticks, a correction needs to be applied to the exposure time because the camera requires a finite time to ramp up the high voltages. This rise time may vary slightly as a function of camera, and voltage level, though typically has an average value of 120 ms (Oliversen 1991). So the shortest possible exposure for point-source (untrailed) spectra is about 0.29 s. This turned out to be the approximate exposure time needed for an optimally exposed spectrum (without overexposure) of both σ Per and σ Sco with the LWP camera. Two OBC ticks, corresponding to a true exposure time of about 0.70 s, were used for the SWP images. Multiple images in the large aperture were obtained to make better use of the camera prep time.

The *IUE* images are listed in Table 1. All data were extracted using the weighted slit extraction routine

TABLE 1. Ultraviolet data used (aperture).

Star		<i>IUE</i> image numbers
HD 23180	σ Per	SWP45515($2 \times L$), SWP45516($2 \times L$), LWP23842($2 \times L$)
HD 147165	σ Sco	SWP45517($2 \times L, S$), LWP23843($2 \times L, S$)
15 CMa	Standard	SWP37270(L), LWP16688(L)

OPTIMAL (Kinney *et al.* 1991) available at the University of Colorado Regional Data Analysis Facility. This routine produces the highest quality (as determined by the signal-to-noise ratio) spectrum that can be extracted from the *IUE* line-by-line, two-dimensional images. The use of OPTIMAL results in higher signal-to-noise by use of a more sophisticated fit to the profile perpendicular to the dispersion direction, while still preserving total flux, and removing most of the cosmic ray spikes. The benefits of using OPTIMAL are most apparent in the very-low signal regions of the spectrum. This is important for this project since the most variable features of typical extinction curves lie in the least sensitive areas of the *IUE* camera (through the 2175 Å bump and the FUV).

All images were corrected for camera degradation. The corrections were based on the studies of Teays and Garhart (1990), and Bohlin & Deutsch (1991) for the LWP and SWP cameras, respectively. There may be an added uncertainty in the absolute flux calibration for these spectra due to the shortness of the exposures and the variable voltage ramp up time of the OBC. All of the spectra are complete down to 1150 Å. However, data between 1180 and 1250 Å have been removed due to contamination from the Ly- α line. The *IUE* data are plotted in Fig. 1 along with the *OAO* and *ANS* data. Corrections were applied to the *OAO* and *ANS* data based on the *IUE* photometric standard scale to allow direct comparison (Bohlin & Holm 1984). For the most part, good agreement is found, indicating the calibration of the *IUE* data was done properly. However, for σ Sco between 1250 and 1400 Å the *OAO* flux is about

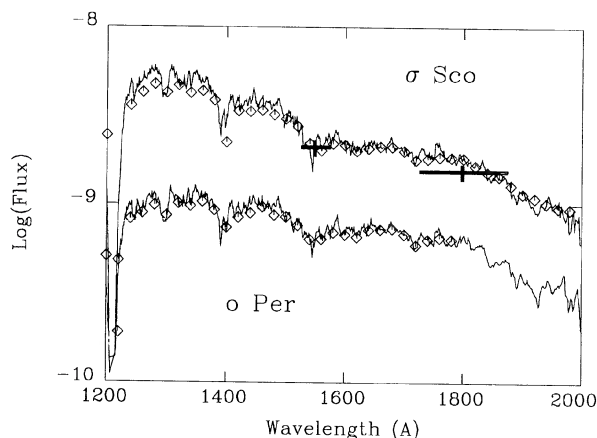


FIG. 1. The *IUE* spectra (solid line) plotted with *OAO* data (diamonds) for σ Sco and σ Per. The crosses mark the *ANS* data for σ Sco, where the width of the bar indicates the band over which the flux was obtained.

15% below the *IUE* flux. The difference is not likely related to the uncertainty in the absolute calibration of *IUE*, which is about 10% (Bohlin 1985). Any such difference should not have a wavelength dependence as is observed between the *IUE* and *OAO* data for σ Sco.

3. THE UV EXTINCTION CURVES

3.1 Previous Work on UV Extinction

Almost every UV satellite [*OAO*, *Copernicus*, *TD-1* (Pajaj *et al.* 1991), *S59* (Viotti & Lamers 1975), *ANS*, *S2/68* (Carnochan 1986)] has been used for extinction studies of σ Sco and o Per. However, only the *OAO* and *Copernicus* data have the spectral resolution and wavelength coverage required for extensive study of the UV extinction.

A complete extinction curve from 1050 to 3600 Å using *OAO* data for σ Sco was presented by Bless & Savage (1972). This extinction curve was made by comparing σ Sco with two different lightly reddened stars, β Cen (B1 III) in the FUV and α Vir (B1 III–IV+B2 V) in the near UV. *Copernicus* data for σ Sco were used to construct an extinction curve from 1000 to 1400 Å and 1885 to 2850 Å (comparison star β CMa, B1 II–III) (Snow & York 1975). The agreement with the Bless & Savage (1972) curve is good. The entrance slit in *Copernicus* was 0.3"×39" much smaller than the *OAO* aperture (8'×1.5"). The good agreement between the *OAO* and *Copernicus* curves seems to eliminate the possibility that the anomalous curve found toward σ Sco is the product of nebular contamination (Snow & York 1975).

The *OAO* data for o Per were obtained only in the FUV spectrometer, 1200–1850 Å (Meade & Code 1980). Extinction curves using these *OAO* data (comparison star 15 CMa, B1 III), and also from *Copernicus* data, 1000 to 1400 Å (comparison star β CMa, B1 II–III), were published by Snow (1976).

ANS data are available for σ Sco but not o Per (Meyer & Savage 1981; Savage *et al.* 1985). These data are in 5 bands from 1550 to 3300 Å. They are in agreement with the *OAO* and *Copernicus* data showing weak FUV and normal bump extinction. Finally, *Voyager* UVS data were obtained for σ Sco allowing extinction to be calculated from 925 to 1150 Å and 1350 to 1680 Å (Snow *et al.* 1990).

3.2 New Extinction Curves

As discussed above, substantial previous work has been done on UV extinction toward σ Sco and o Per. The new *IUE* data are very important, first because they allow a careful spectral-type matching to be done with comparison stars from the extensive *IUE* archives. Second, it allows us to construct extinction curves which are directly comparable to the FM and CCM extinction work. Third, no data on the bump region of o Per exist from any previous studies.

The UV extinction toward o Per and σ Sco are determined here using the "pair method" (FM). Accurate spectral typing is of great importance since σ Sco and o Per are both spectroscopic binaries. The spectral type of σ Sco is

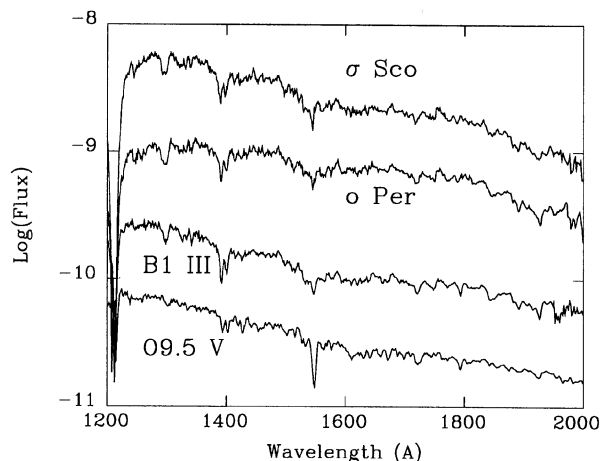


FIG. 2. Log Flux plots of σ Sco and o Per, along with the spectra of two dereddened comparison stars showing the spectral features typical of B1 III and O9.5 V stars. Some of the more obvious stellar features include, the merged Si III lines around 1300 Å, the Si IV doublet near 1400 Å and the C IV doublet near 1550 Å. A very close spectral match is seen between σ Sco, o Per, and the B1 III comparison star (15 CMa).

B1 III+O9.5 V and it is a β Cep star (Pigulski 1992). Chapellier & Valtier (1992) suggest that σ Sco is pulsating in a single nonradial mode modulated by the orbital frequency of the binary system. The apparent visual magnitude of the O9.5 V companion is about 2 mag dimmer than the primary. Curiously, o Per is also a spectroscopic binary with a period of 4.4 days, with a spectral type of B1 III for the primary (Wood *et al.* 1980; Abt & Cardona 1984). The secondary is possibly B1 V (Foy 1972).

The uncertainties in spectral type of σ Sco and o Per require a careful choice of an unreddened comparison star. Using stars from the *IUE* archive, careful UV spectral typing was done for o Per and σ Sco (Rountree & Sonneborn 1991). We examined numerous B0.5, B1, and B1.5 giant and subgiant stars from the archives and found the B1 III star, 15 CMa, to be the best match to the UV spectral features of both o Per and σ Sco (see Fig. 2). This lightly reddened star was also used as the comparison star for o Per in the *OAO* study (Snow 1976). Images of 15 CMa were obtained from the *IUE* archives (see Table 1). Besides being an excellent spectral match, 15 CMa was chosen because it had one of the cleanest (highest signal-to-noise) spectra with the smallest reddening [$E(B-V) = 0.04$].

As described in Sec. 3.1, there are *OAO* data (1050–3600 Å) and *Copernicus* data (1000–1400 Å, 1885–2850 Å) for σ Sco. For o Per, less wavelength coverage is available, 1200–1850 Å for *OAO*, and 1000–1400 Å for *Copernicus*. The *Copernicus* data have about the same photometric accuracy, perhaps 10% (Snow & York 1975) as the *IUE* data but the *OAO* data have the potential for more accurate extinction curves, being accurate in general to 1% or 2% (Bless & Savage 1972). For o Per the better wavelength coverage with *IUE* demands the use of those data. *OAO* data for 15 CMa, chosen here as the best spectral match using the *IUE* data, are available only for 1200–

1850 Å and the data are suspect having been obtained during the high background South Atlantic Anomaly and during daylight (Meade & Code 1980). The other lightly reddened stars of similar spectral type for which *OAO* data are available are β CMA, ξ^1 CMA, β Cep, α Vir, β Cen, and ϵ Cen. All are listed in Code & Meade (1979) as B1 III stars with the exception of α Vir which is listed as B1 V. It is included here because Bless & Savage (1972) used it as a comparison star for their σ Sco extinction curve. The *OAO* data are published in 20 Å bins unsuitable for spectral classification and none of these stars with the exception of ξ^1 CMA have well-exposed low-dispersion *IUE* spectra. As a result, accurate UV spectral types cannot be obtained for these stars. The *IUE* spectra of ξ^1 CMA indicate that it is not a giant star. Therefore, in the following discussion, we construct and analyze extinction curves using *IUE* data only for both the reddened and unreddened stars.

In Fig. 2, we have plotted the spectra of σ Per, σ Sco, and 15 CMA (dereddened) together, over the range 1200–2000 Å to illustrate the well-matched stellar features. What is immediately apparent from this figure is that the FUV of the reddened star, σ Sco, shows nearly the same spectral slope as the dereddened standard star, 15 CMA. One possibility is that the O9.5 V companion of σ Sco could be adding significant extra flux in the FUV. There is no sign of any O9.5 V features in the σ Sco UV spectrum. The dereddened spectrum of HD 38666, a O9.5 V with $E(B-V) = 0.02$, is also shown in Fig. 2 for comparison. The B1 III and O9.5 V stars have almost identical slopes in the FUV. We studied the effects of using the O9.5 V star as the unreddened standard alone, and in combination with the B1 III star. They produce nearly identical extinction curves, except for the presence of poorly matched spectral features (leading to spurious small structure in the extinction law) when the O9.5 V spectrum was used. We conclude that even if the O9.5 V companion is contributing significant flux in the FUV, it will have no significant effect on the resulting extinction curve. Similarly, contamination from the B1 V companion of σ Per is not likely to have a significant effect on its extinction curve.

The pair method used here is subject to both random and systematic errors, which have been outlined by Massa *et al.* (1983). The largest of these is due to spectral mismatch. When using hot stars, these errors are smaller because of their similar spectral slopes. A good spectral match is demonstrated when smooth extinction curves are derived. Spectral mismatch can cause spurious features due to unmatched stellar features and can cause either a slight slope change or offset. The well-matched spectral features for σ Sco and σ Per indicate that the match is reasonably good.

A fundamental improvement to the general study of UV extinction properties has been an analytic fitting of the curves, developed in a series of papers by FM. The parameterization uses a linear combination of a Drude bump profile, which fits the strength, width (γ), and position (λ_0^{-1}) of the bump, a linear background, and a FUV curvature function to describe the extinction profile. With this fit of 6 independent parameters, the characteristics of dif-

TABLE 2. Extinction curve data.

Star	$E(B-V)$	λ_0^{-1} ^a	γ^a	Curve coefficients			
				c_1	c_2	c_3	c_4
HD 23180 (σ Per)	0.32	4.66	1.26	0.36	0.65	5.65	0.66
HD 147165 (σ Sco)	0.40	4.59	0.96	1.01	0.30	3.52	0.060
Errors ^b	...	0.015	0.056	0.45	0.10	0.36	0.10

^aThe CCM average values are $R_v = 2.8$: $\lambda_0^{-1} = 4.61$, $\gamma = 0.99$, and $R_v = 3.8$: $\lambda_0^{-1} = 4.60$, $\gamma = 0.98$.

^bFrom Table 7, Fitzpatrick & Massa (1990) scaled to $E(B-V) = 0.36$.

ferent extinction curve profiles can be compared directly and analytically. We have fit our UV extinction curves with the FM parameterization and list the fits and their errors in Table 2. Fits to the σ Per bump were performed with and without including the noisy data in the 2000–2200 Å region. There was no significant difference between the values of bump width and central wavelength between the two fits. The values of the FM parameters listed in Table 2 are normalized to $E(B-V)$ for easy comparison to earlier studies. Conversion from the FM parameterizations, for curves normalized to $E(B-V)$, to curves normalized to $A(V)$ is: $a_1 = c_1/R_v + 1$, $a_2 = c_2/R_v$, $a_3 = c_3/R_v$, $a_4 = c_4/R_v$ (MC).

The value of R_v has been calculated for both stars from near-IR photometry. The values are 3.8 for σ Sco (CCM) and about 2.8 for σ Per (Strom *et al.* 1974). The R_v value for σ Per is somewhat uncertain because the near-IR photometry shows evidence for an IR excess (Whittet & van Breda 1980). An additional uncertainty affecting both stars is that the near-IR intrinsic colors of B1 III stars are not well known. Neither Johnson (1966) nor Koornneef (1983) list colors for early giants. Calculations of R_v for σ Sco and σ Per assume that B1 III stars have the same intrinsic near-IR colors as dwarf stars.

We have plotted the interstellar extinction toward the stars from 3 to 9 μm^{-1} , normalized to $A(V)$, in Fig. 3. Total visual extinction, $A(V)$, was determined from R_v and $E(B-V)$. Plotted in Fig. 3 are the data, the FM fits, and

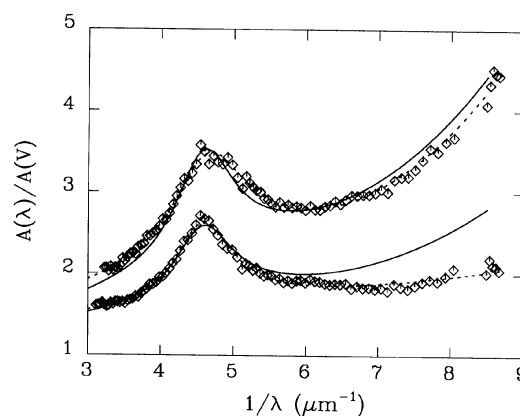


FIG. 3. *IUE* derived extinction curves (diamonds) for σ Per and σ Sco are shown plotted with the CCM R_v -dependent extinction laws (solid line), $R_v = 2.8$ for σ Per, and $R_v = 3.8$ for σ Sco, and the FM fits (dashed lines).

the average CCM curves for the R_v values of σ Per ($R_v = 2.8$) and σ Sco ($R_v = 3.8$).

4. DISCUSSION

Figure 3 and the FM fits in Table 2 show that the σ Per curve follows the average CCM curve closely through the FUV but the bump is significantly broader than the average and is shifted to smaller wavelengths. The σ Sco extinction follows CCM closely in the bump region but falls below the average curve in the FUV. We believe this deviation from the R_v -dependent curve in the FUV to be real, not an artifact of contamination from the secondary star, spectral mismatch or nebular contamination (as discussed above). The difference between the average CCM extinction and the observed extinction at 1200 Å is about 0.7 (see Fig. 3). The difference between the *IUE* and *OAO* absolute flux calibration of about 15% cannot account for this deviation. If the *OAO* flux is adopted, the difference is still 0.6. CCM found a similar deviation using *Copernicus* data. They estimated that the σ Sco curve lies about 2σ below the CCM curve.

The σ Per sight line is in or near the Per OB 2 (II Per) association and the ξ Per group but its proper motions indicate it is not a member. It is only moderately reddened with an $E(B-V) = 0.32$ and lies projected on the sky between two Barnard clouds (Blaauw 1952). BD+31°643 lies only 8' away but is more highly reddened. Blaauw suggests that unless the cloud in front of BD+31°643 is very sharp edged, σ Per lies in front of the cloud. There is a hole in the CO at the position of σ Per suggesting the possibility that the star and cloud are physically related (Crutcher 1976). The measured IR excess for σ Per also indicates a possible close connection between the star and dust. However, the observed heating of the cloud edge and the absence of CO radial velocity trends indicates that σ Per must be at least a few pc away from the cloud (Crutcher 1976; Bachiller *et al.* 1987). Interstellar line studies imply strongly that the σ Per dust is associated with the cloud near IC 348 (Strom *et al.* 1974). It is likely that σ Per lies well behind the cloud (Snow 1976; Snow *et al.* 1993). Therefore there may be some similarity to the HD 62542 sight line where the star is seen through a cloud with which it is not physically connected (Cardelli *et al.* 1990). The BD+31°643 extinction curve is somewhat different, R_v is 3.3, and the bump is not as broad, ($\lambda_0^{-1} = 4.60$; $\gamma = 1.15$) (Snow *et al.* 1993).

The σ Sco sight line is part of the Upper Scorpius region (Sco OB 2) of the Scorpio-Centaurus association which also includes ρ Oph (Garrison 1967). It is one of the earliest stars in this association and is surrounded by a H II region (Sharpless 9) indicating that σ Sco is in close proximity to the surrounding gas and dust from which it may have formed (de Geus 1992). Gaylard (1984) suggests that the O9.5 V secondary produces most of the ionizing UV flux creating this H II region. The σ Sco stellar system is located close to the edge of a dense molecular cloud. The H II region is ionization bounded toward the cloud and

density bounded toward the east and south. The molecular cloud near σ Sco extends to include the cloud near ρ Oph (Cappa de Nicolau & Poppel 1986).

While most sight lines follow CCM to within a standard deviation, larger deviations from the average curve do occur which are correlated with environmental effects. In the bump wavelength region, these deviations can be measured in the strength [$A(2200)/A(V)$], width (γ), and central wavelength (λ_0^{-1}) of the bump. CC found that the dark cloud lines of sight show a tendency toward smaller deviations around the bump as measured by $A(2200)/A(V)_{\text{obs}} - A(2200)/A(V)_{\text{CCM}}$. The σ Per bump ($\lambda_0^{-1} = 4.66$; $\gamma = 1.26$) is similar to that seen in VCT 10 ($\lambda_0^{-1} = 4.72$; $\gamma = 1.24$), HD 62542 ($\lambda_0^{-1} = 4.74$; $\gamma = 1.24$) and HD 29647 ($\lambda_0^{-1} = 4.70$; $\gamma = 1.42$) which represent DC sight lines (CC; Cardelli & Savage 1988). The bumps in all these stars are broader than the CCM average (see Table 2) for their respective R_v values and are shifted to shorter wavelengths. The σ Sco bump parameters are the same as the average CCM values within the errors.

In the FUV, deviations from the CCM average are seen in the total extinction [$A(1200)/A(V)$] and in the extinction slope from 1500 to 1200 Å. CC show that lines of sight through BN have smaller deviations in the FUV [$A(1200)/A(V)_{\text{obs}} - A(1200)/A(V)_{\text{CCM}}$] than DC lines of sight which tend to show positive deviations. The deviation at 1200 Å for σ Sco (-0.7) is the most negative yet seen. The largest value in the CC sample is -0.24 for HD 193322, a BN line of sight. The uncertainty (1σ) in the average CCM curve at this wavelength is 0.3–0.4 (CCM). Although not as large, ρ Oph shows a similar deviation (Snow *et al.* 1993). The ρ Oph and σ Sco sight lines are sampling opposite edges of the same cloud. Although large, the deviations in the FUV slope seen in ρ Oph and σ Sco are not consistent with those seen along other BN lines of sight. MC find that the slope of the deviations in the FUV is quite different for BN and DC lines of sight with diffuse lines of sight in between. The σ Sco and ρ Oph extinction curves show behavior more similar to the DC/diffuse lines of sight. The σ Per extinction curve shows no significant deviations from the average CCM curve in the FUV.

Although σ Sco lies in a H II region, it is powered only by a B1 III+O9.5 V system. The lines of sight showing the BN behavior all have nearby O stars providing a very strong UV radiation field. The FUV deviations cannot be explained solely in terms of varying the grain size distribution, the possible exception being the BN sight lines. (MC). One possible interpretation is that coatings are present on the DC dust and to a lesser extent the diffuse cloud dust. Exposure to intense UV radiation removes the coatings in the BN. In this scenario, the slope deviations seen for σ Sco indicate that the UV radiation field is not strong enough to remove all the coatings. The large negative value of $A(1200)/A(V)$ measured for σ Sco may be indicative of more than just variable coatings on grains. Cardelli & Clayton (1988) considered dust in the Orion trapezium, a similar environment to σ Sco where a hot star is very close to a molecular cloud and to the dust along the line of sight. They suggested that an unusual grain size

distribution could be created by preferential evaporation or sputtering, or by size-dependent acceleration of grains due to radiation pressure.

How do σ Sco and o Per compare with other sight lines? The general properties of the σ Sco- and ξ Oph-type dust environments have been summarized by Snow (1992). The σ Sco clouds have flat FUV extinction, are associated with star formation; have strong bumps; weak CN, and detectable Fe I. The ξ Oph clouds have steep FUV extinction, wider and weaker bumps, strong CN, and no Fe I. In some ways, these criteria distinguish the BN (σ Sco) and DC (ξ Oph) dust as discussed above. Using the CN/Fe I ratio, the σ Sco-type includes ρ Oph and o Per, while the ξ Oph type includes HD 29647 (Joseph *et al.* 1989). This ratio implies that more molecules occur along DC lines of sight under the assumption that densities and shielding from UV radiation are higher. The bump differences between DC and BN discussed above are also included as criteria. The flat and steep FUV slopes are related to R_v and not particularly to BN, DC, σ Sco, or ξ Oph dust. However, as

discussed above the DC and BN sight lines do show systematic but different deviations from CCM.

The fact that σ Sco and o Per fall more or less in the same type using the σ Sco/ ξ Oph scheme indicates what Snow (1992) pointed out that all sight lines do not fall neatly into one class or the other. There are in fact no easily defined cloud types. The σ Sco, ξ Oph, BN, and DC cloud types do not have physical meaning except as examples of a continuum of dust environments. The various observable characteristics of interstellar dust such as R_v , γ , λ_0^{-1} , and FUV extinction slope combine in different ways based on many different environmental variables. Among the most important of these may be: the amount of dust, the size distribution of the dust, the cloud density, and strength of the local UV radiation field.

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