1991

Diffuse band profiles in the spectrum of HD 29647: Evidence for a molecular origin?

Theodore P. Snow

C G. Seab

University of New Orleans

Recommended Citation

Astrophys. J. 382 189 (1991)

THE ASTROPHYSICAL JOURNAL, 382:189–192, 1991 November 20

DIFFUSE BAND PROFILES IN THE SPECTRUM OF HD 29647: EVIDENCE FOR A MOLECULAR ORIGIN?

THEODORE P. SNOW[1]
Center for Astrophysics and Space Astronomy, University of Colorado, Campus Box 391, Boulder, CO 80309

AND

C. G. SEAB[1]
Department of Physics, University of New Orleans, Lakefront, New Orleans, LA 70148
Received 1990 August 23; accepted 1991 May 10

ABSTRACT

High signal-to-noise ratio spectra have been obtained of the diffuse interstellar bands at 5780 and 5797 Å in the spectrum of HD 29647, a heavily reddened star within or behind a portion of the Taurus dark cloud complex. The observations were made using the coudé spectrograph on the Canada-France-Hawaii Telescope. The Reticon detector combined with the coudé spectrograph and excellent observing conditions allowed S/N ratios as high as 200 for this star, which was $V = 8.37$ and $E(B-V) = 1.03$. In two separate exposures both bands were found to be narrower and weaker than normal values for stars of similar reddening, and the profiles appear to deviate from those normally seen as well. Theories of band formation due to absorption centers in solid grains require bandwidths much greater than observed in HD 29647 and predict profile variations with grain size that are quite different from what is seen. Therefore we suggest that these observations argue for a molecular origin for the diffuse bands. The observed profiles may be explained as due to unusual rotational excitation in molecules.

Subject headings: interstellar: grains — interstellar: matter — line profiles — stars: individual (HD 29647)

1. INTRODUCTION

The diffuse interstellar bands present astronomers with a mystery that is now well over 50 years old. As early as 1934 the first of what is now recognized as a broad family of unidentified interstellar absorption features was noticed (Merrill 1934). While the breadth of the features (as great as 20 Å in the case of the 4430 Å band; Herbig 1975) led early researchers to consider molecular bands as leading candidates for the carriers, later attempts at identification have tended to focus on absorption centers in solid grains (e.g., Herbig 1975, and references therein). One reason for this is that physical chemistry considerations make it difficult to understand how large abundances of complex molecules could arise in the diffuse interstellar medium; another is that despite many attempts, no fine structure such as might be present due to molecular band rotational structure has ever been convincingly demonstrated. This point in particular has effectively ruled out small and simple molecules, such as the ubiquitous diatomic species CN, CH, CH^+, CO, H_2, and C_2, since all of these species have pronounced rotational line structure.

Despite the generally negative outlook for molecular origins of the diffuse bands, several researchers have kept this possibility open, citing: (1) the large cross sections for molecular formation via ion-molecule reactions, which were unknown at the time the diffuse bands were discovered; (2) the difficulty under the grain-formation hypothesis in explaining the small width of some of the bands, such as those at 6196 and 6614 Å; (3) the lack of strong correlations between the strengths of the diffuse bands and ultraviolet extinction due to (presumably) small grains (Witt, Bohlin, & Stecher 1983; Seab & Snow 1984); and (4) the recent discovery that some very large and complex molecules (such as the polycyclic aromatic hydrocarbons, or PAHs) might be quite abundant in the diffuse interstellar medium (Donn 1968; Duley & Williams 1981; Leger & Puget 1984). In addition, mechanisms for producing broad features devoid of fine structure from even rather small molecules have been proposed (e.g., Douglas 1977; Danks & Lambert 1976; Smith, Snow, & York 1977).

It has always seemed significant that selected lines of sight demonstrate very unusual behavior, compared to the normal correlations between diffuse band properties and other parameters such as color excess. Any successful explanation of diffuse band origins must take these special cases into account. The present paper reports some results from our observations of one of the most special cases of all, the line of sight toward the star HD 29647. It has been established previously that this star has peculiar extinction properties (e.g., Snow & Seab 1980; Goebel 1983). Here we report our observations of diffuse interstellar band profiles along this very unusual line of sight.

The next section describes the observations to be discussed; § 3 presents the basic results; and § 4 summarizes the implications we feel are dictated by those results.

2. THE OBSERVATIONS

HD 29647 is a late Bp star, most recently classified as a B6-7IV Hg–Mn star (sources summarized by Crutcher 1985). It is located in the Taurus dark cloud complex. It has $V = 8.37$ and color excess $E(B-V) = 1.03$. Previous studies have revealed unusual extinction characteristics in the ultraviolet, where little or no evidence of a 2175 Å extinction bump is seen and the far-UV extinction rise is steeper than normal (Snow & Seab 1980); in the visible, where an abnormally large ratio of total to selective extinction is found (as summarized by Crutcher 1985); and in the infrared, which shows an absorption feature due to water ice (Goebel 1983). Extensive optical and radio spectroscopy of interstellar features in this line of sight

[1] Guest Observer, Canada-France-Hawaii Telescope.

was reported by Crutcher (1985), who found large depletions of several elements (and who also found, unfortunately, that the photospheric lines, which are very abundant in this peculiar star, are also very sharp, making it difficult to distinguish stellar from interstellar lines).

The data discussed here were obtained at the Canada-France-Hawaii Telescope in 1989 September. The CFHT is a 3.6 m instrument; we used the coudé spectrograph and Reticon detector system, which together yield an effective (2 pixel) spectral resolution of 0.14 Å (about 7.5 km s^{-1}) at 5780 Å. Observing conditions were excellent, with seeing disks of about 0".5 during each of our 3 nights. The CFHT Reticon yields very high S/N for short-to-moderate-duration exposures, which are dominated by readout noise.

Data reduction was carried out at the Colorado Astrophysics Data Analysis Facility, using routines developed in the IDL language for CFHT reductions. The reductions are quite straightforward; dark counts are subtracted, divisions by flat-field spectra obtained at the telescope are done to eliminate fixed-pattern noise, and wavelength calibrations are derived from neon-argon lamp spectra obtained at the telescope.

For our two exposures on HD 29647 (of 1800 and 3600 s on the nights of 1989 September 14 and 15, respectively) the S/N levels were approximately 50 and 200, respectively. These S/N levels were determined independently by direct measurement of the rms fluctuations in the continuum near the observed features and from the standard calibration of S/N versus counts/pixel provided by the CFHT user's manuals. Both methods yielded comparable values for S/N.

3. RESULTS

Figure 1 shows the profiles of the 5780 and 5797 Å diffuse bands in HD 29647. The two separate exposures are displayed individually, to illustrate the reality of the salient features. Also shown are band profiles observed during the same run for HD 183143, the prototypical diffuse band star (e.g., Herbig 1975) and for BD +31°643, a heavily reddened star embedded in IC 348, a dark cloud cluster in Perseus (Strom, Strom, & Carrasco 1974).

The wavelength scale is heliocentric. The Na I *D* lines were included in the exposures (but are not shown in Fig. 1), which allowed us to measure the diffuse band wavelengths in the frame of reference of the cold gas along the lines of sight. The results of doing so are discussed below.

Figure 1 shows that the profiles of the 5780 and 5797 Å features in HD 29647 differ markedly from those in the other stars. The 5780 Å feature shows an asymmetric profile having an extended red wing, while the 5797 Å band is symmetric; these characteristics are similar to those found in other stars (e.g., Savage 1976; Snell & Vanden Bout 1981; Westerlund & Krelowski 1988). The 5780 Å band has a narrow core whose FWHM is approximately 0.18 Å (which is comparable to the instrumental resolution) and a broader base whose FWHM is about 1.9 Å (there is a second feature of similar width near the long-wavelength edge of the broad shallow band). The 5797 Å band toward HD 29647 has a cleaner profile, lacking any sharp cores. This feature has a FWHM of 0.5 Å.

The sharp core of the 5780 Å band is almost certainly stellar. Its width is similar to those of other sharp lines nearby, which are probably stellar. Unfortunately, line lists in this wavelength region for HG–Mn stars do not exist, so it has been difficult to identify these features. Bidelman (1990, private communication) points out that a line appears at 5780.15 Å in the somewhat cooler Ap star 78 Virginis, suggesting that the sharp spike on our observed 5780 Å band is the same feature (one possible identification is Fe II; Kurucz [1981] lists numerous

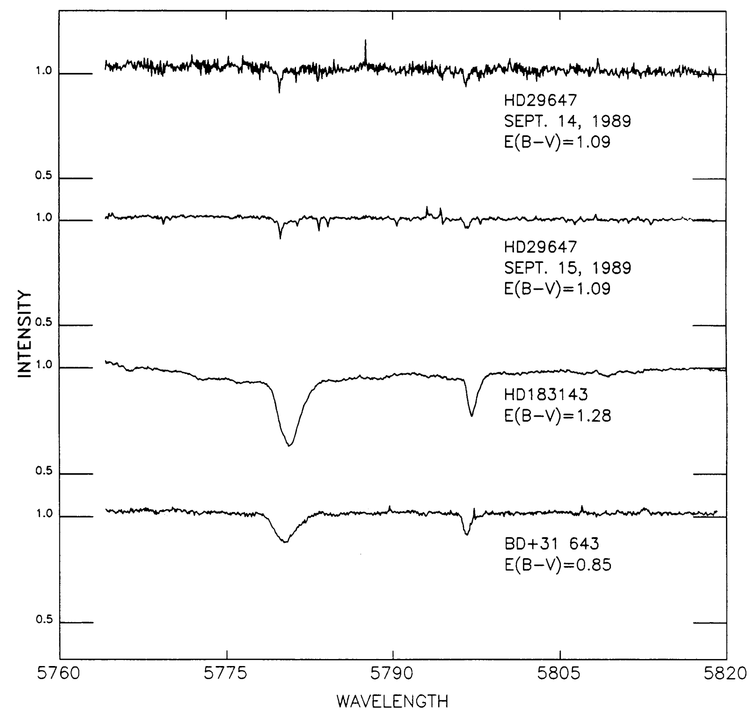

FIG. 1.—The 5780 and 5797 Å diffuse band profiles. Upper two plots show the bands in the two separate spectra obtained for HD 29647; below these are the bands observed toward HD 183143 and BD 31°639. Velocity scale is heliocentric; the apparent shifts in wavelength between the diffuse bands from one star to another are due largely to different interstellar cloud velocities, as measured in the reference frame of the Na I *D* lines (not shown). The sharp absorption spike superposed on the 5780 Å band in ths spectrum of HD 29647 is almost certainly a stellar line.

strong Fe II lines which coincide not only with this feature but also appear to match several of the other sharp features in our spectrum of HD 29647).

Neglecting the sharp spike on the 5780 Å feature, both bands are narrower (by about 20% for the 5780 Å feature and a factor of 2 for the 5797 Å band) in the spectrum of HD 29647 than in the spectra of the comparison stars (HD 183143 has line widths of 2.5 and 1.0 Å, respectively, while BD +31°643 has 1.9 and 0.46 Å, respectively).

Figure 2 shows enlarged profiles for the two bands, unsmoothed (*upper*) and smoothed (by 10 pixels; *lower*). In the smoothed version, the sharp spikes at 5780.2 and 5782 Å were removed before smoothing. Here the asymmetric profile of the 5780 Å band is more readily seen than in Figure 1. This profile appears to differ from the intrinsic profile derived by Westerlund & Krelowski (1988); our data show an extended red wing, whereas the 5780 Å profile presented by Westerlund, & Krelowski is nearly symmetric (although the authors note that the blue side is slightly steeper; i.e., they claim a slight extension of the red wing compared with the blue). The extra absorption on the red side of the band in HD 29647 is most likely intrinsic; stellar lines are far too sharp in this star to create such a broad feature, and the Na I *D* lines (see Fig. 1) show no sign of any velocity components to the red.

On the contrary, the 5797 Å feature in HD 29647 appears very nearly symmetric, whereas Westerlund & Krelowski (1988) report a markedly asymmetric profile with an extension to the red.

The equivalent widths of both bands are much smaller toward HD 29647 than expected for the line-of-sight reddening. Standard correlations between $E(B-V)$ and diffuse band strengths (e.g., Krelowski & Walker 1987; Josafatsson & Snow 1987; Seab, Snow, & Krelowski 1991) would suggest equivalent widths of roughly 450 mÅ for the 5780 Å band and 150 mÅ for the 5797 Å feature, whereas the measured values from our data are 43 mÅ and 33 mÅ, respectively. We note that the broad diffuse band at 4428 Å has previously been reported to be weak in this line of sight (Snow 1973; in that paper the star was identified only as BD +25°723).

4. DISCUSSION

We note that the weakness of the 5780 and 5797 Å bands toward HD 29647, relative to the reddening and total extinction, is unprecedented. Previous authors (e.g., Wampler 1966; Snow & Cohen 1974; Krelowski & Westerlund 1988) have pointed out that the relative strengths of the diffuse bands in dense clouds are low, but no effect as dramatic as reported here has previously been found. The extinction is greater than in most other cases, and the ratio of observed band strength to that expected from "normal" correlations is far smaller. The present result is so striking as to suggest a complete decoupling of the diffuse band carriers from the dust grains that produce visual extinction.

The 5780 and 5797 Å bands toward HD 29647 share the common trait that they are very weak with respect to normal correlations with dust extinction, and they both have unusual profiles, but they differ greatly in the nature of their profiles. The 5780 Å band shows a more extended red wing than the normal profile, which is nearly symmetric, whereas the 5797 Å band is nearly symmetric, instead of having the normal red wing. This contrast lends further support to the idea that these two bands have different carriers (Krelowski & Walker 1987; Josafatsson & Snow 1987).

The interpretation of the reported data is complex and cannot be definitive at this time. Nevertheless, some broad conclusions may be justified. In various discussions of the diffuse bands as due to absorption centers in solid grains, it has consistently been stressed that features due to such carriers cannot be very sharp, due to solid-state energy-level smearing (e.g., Smith et al. 1977, and references therein). It has also been generally predicted that solid-state features should, under some conditions (particularly where grains are enlarged, as is likely in the line of sight toward HD 29647), show emission wings. Such emission has never been reliably reported, and its

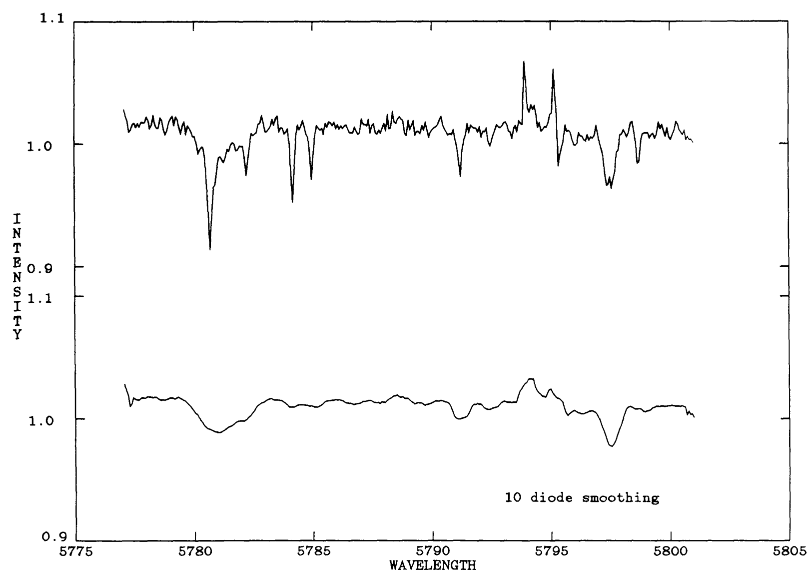

FIG. 2.—Enlarged profiles of the 5780 and 5797 Å bands toward HD 29647. Upper plot shows the same data as seen in Fig. 1, on an expanded scale. In the lower plot the sharp features superposed on the 5780 Å band have been removed (with straight-line interpolation substituted across the resulting gaps), and the data have been smoothed by a 10 pixel boxcar.

absence in at least one recent study (Seab & Snow 1991) has been used to rigorously rule out some classes of dust grain models. Furthermore, our results show that the shapes of the bands, as well as their central wavelengths, are remarkably constant, another difficulty for the solid-state absorption hypothesis (see discussion in Smith et al. 1977). These facts lead us to conclude tentatively that the bands are most likely not formed by any type of solid-state absorption process. We believe that a molecular origin is more likely.

We can speculate a bit as to the explanation for the unusual behavior of the diffuse bands in this line of sight. HD 29647 is already known to have a very weak 2175 Å extinction bump (Snow & Seab 1980), and also to have water ice mantles on the grains (Goebel 1983). These results have generally been interpreted as meaning that coatings on the grains have supressed the UV extinction bump. If the diffuse bands were also due to grains, then the same interpretation could be offered for our current results, that is, that coatings on the grains have suppressed the absorption centers in the grains, weakening the bands. This seems unlikely, however, since the diffuse bands are still present, but with reduced widths. As already noted, grain growth would be expected to broaden the features of cause emission wings. Hence we infer from these observations that a grain origin for the 5780 and 5797 Å diffuse bands is less likely than a molecular origin. If this is correct, then some other explanation for their weakness in this line of sight must be sought.

In view of the very rich and complex chemistry of the dark cloud region with which HD 29647 is associated (the largest interstellar molecules, the cyanopolyenes, have been detected near this star, in the Taurus TMC-1 complex [e.g., Bell & Mathews 1985; Avery 1980]), it seems counterintuitive that a molecular carrier of the diffuse bands should be underabundant in this region. We can offer several possible explanations, however: (1) the diffuse bands are formed by a molecular ion, which would be more abundant outside cloud cores, where ionizing radiation would be more prevalent; (2) the responsible molecules require activation energy for their formation, which is absent inside the Taurus molecular cloud (in this regard it is noteworthy that Crutcher [1985] reports no detection of CH^+, which implies that shocked gas is not present); or (3) the molecules that form the diffuse bands are frozen out onto grain surfaces in cold, dense regions such as the Taurus clouds (recall that the infrared water ice feature has been detected toward this star).

The narrow widths of the bands toward HD 29647 could be due to a somewhat low rotational excitation temperature for the remaining free molecules in the cloud. One possible test of this hypothesis might be to measure the rotational excitation of other species along this line of sight. This will, however, be made difficult by the numerous sharp stellar lines in the spectrum.

Whatever the ultimate explanation of our results, the unusual profiles and strengths of the diffuse bands toward HD 29647 appear to favor a molecular origin of the bands. We are continuing our observational program, in hopes of finding further evidence that might help to isolate the nature of the diffuse band carriers.

This research has been supported by NSF grant AST 8505587 to the University of Colorado, and by funds provided through the NSF grant NSF/LaSER (1989)-RFAP-08 to the University of New Orleans. We are grateful for the access to the Canada-France-Hawaii Telescope provided through the courtesy of the Canadian National Research Council, and for the observing assistance provided by Jean Arnaud and Tom Gregory of the CFHT staff. We are grateful to Charles Cowley and especially to W. Bidelman for helpful discussions of the identification of stellar lines in our spectra. Data reduction and analysis assistance were provided by Krista Lawrence and Robert Rudloff at the University of Colorado.

REFERENCES

Avery, L. W. 1980, in IAU Symp. 87, Interstellar Molecules, ed. B. H. Andrew (Dordrecht: Reidel), 47
Bell, M. B., & Mathews, H. I. 1985, ApJ, 291, L63
Crutcher, R. M. 1985, ApJ, 288, 604
Danks, A. C., & Lambert, D. L. 1976, MNRAS, 174, 571
Donn, B. 1968, ApJ, 152, L129
Douglas, A. E. 1977, Nature, 269, 130
Duley, W. W., & Williams, D. A. 1981, MNRAS, 196, 269
Goebel, T. H. 1983, ApJ, 268, L41
Herbig, G. 1975, ApJ, 196, 129
Josafatsson, K., & Snow, T. P. 1987, ApJ, 319, 436
Krelowski, J., & Walker, G. A. H. 1987, ApJ, 312, 860
Krelowski, J., & Westerlund, B. E. 1988, A&A, 190, 339
Kurucz, R. L. 1981, Smithsonian Astrophysical Observatory Special Report (Washington: Smithsonian Institution), 390
Leger, A., & Puget, J. L. 1984, A&A, 137, L5
Merrill, P. W. 1934, PASP, 46, 206
Savage, B. D. 1976, ApJ, 205, 122
Seab, C. G., & Snow, T. P. 1984, ApJ, 277, 200
———. 1991, ApJ, submitted
Seab, C. G., Snow, T. P., & Krelowski, J. 1991, in preparation
Smith, W. H., Snow, T. P., & York, D. G. 1977, ApJ, 218, 124
Snell, R. L., & Vanden Bout, P. A. 1981, ApJ, 244, 844
Snow, T. P. 1973, AJ, 184, 135
Snow, T. P., & Cohen, J. G. 1974, ApJ, 194, 313
Snow, T. P., & Seab, C. G. 1980, ApJ, 242, L83
Snow, T. P., York, D. G., & Welty, D. E. 1977, AJ, 82, 113
Strom, S. E., Strom, K. M., & Carrasco, L. 1974, PASP, 86, 798
Wampler, E. J. 1966, ApJ, 144, 921
Westerlund, B. E., & Krelowski, J. 1988, A&A, 203, 134
Witt, A. N., Bohlin, R. C., & Stecher, T. P. 1983, ApJ, 277, L47