DIFFUSE AND

TRANSLUCENT CLOUDS

OPTICAL AND ULTRAVIOLET OBSERVATIONS OF DIFFUSE INTERSTELLAR CLOUDS

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Abstract. Absorption-line studies of diffuse interstellar clouds have recently been invigorated at ultraviolet wavelengths with the Goddard High Resolution Spectrograph (GHRS) on the *Hubble Space Telescope* and at optical wavelengths with efficient high resolution spectrographs and CCD detectors. These instruments have made it possible to explore new regimes in determining the atomic and molecular abundances of diffuse clouds and tracing the velocity structure of interstellar lines. In the case of the atomic gas, the abundances of elements as diverse as oxygen and krypton have been accurately measured with GHRS and are consistent with a local ISM whose metallicity is about 2/3 that of the Sun. GHRS has also provided new insight on molecular processes in diffuse clouds through observations of CO, C_2, HCl, and vibrationally-excited H_2. With velocity resolutions of 0.3 km s^{-1} now attainable, optical spectra of species like CH, CH^+, and CN are beginning to probe the physical characteristics of diffuse clouds in detail. Similar spectra of interstellar Na I toward resolvable binary star systems have recently revealed a rich variety of small-scale structure in the cold diffuse gas.

1. Introduction

A simple definition of a diffuse interstellar cloud is that of a parcel of gas and dust through which one can still see background stars. In more specific terms of extinction, diffuse usually implies $A_V \leq 2$ mag. These clouds provide a simpler environment to test ideas about molecular processes in dark clouds using sub-milli-arc-second pathbeams that can accurately sample both atomic and molecular abundances. In the cold, tenuous gas of dif-

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fuse clouds, essentially all of the atoms, ions, and molecules are in their ground electronic states. By studying the optical and ultraviolet absorption lines produced in stellar spectra by the resonance transitions arising from these states, the composition, chemistry, and physical conditions of the intervening cloud(s) can be deduced. The following observational "wish list" constitutes the basic criteria for maximizing the scientific return from such studies:

1. Since interstellar absorption lines are typically quite narrow, high spectral resolution is essential with optimal values greater than $R = \lambda/\Delta\lambda = 10^5$ or, in terms of velocity, less than 3 km s^{-1}. This degree of resolution is necessary to determine the velocity structure of interstellar line profiles and possibly resolve individual components. High spectral resolution is also essential for specific applications such as the measurement of interstellar isotope ratios and the rotational excitation of interstellar molecules.

2. Since many important interstellar lines are weak ($W_\lambda \leq 10$ mÅ), the acquisition of high signal-to-noise ($S/N \geq 500$) spectra at high resolution is necessary to make convincing detections. The motivation in accurately measuring such weak lines is that they are usually optically thin and therefore easily interpreted in terms of the absorbing atom, ion, or molecule. Since rare species and the low oscillator strength transitions of common species both produce weak lines, high S/N observations are vital to determining accurate abundances in diffuse clouds.

3. The ability to obtain high resolution, high S/N spectra of stars down to increasingly faint limiting magnitudes ($V \geq 10$) is important in that it opens up a much larger and more diverse range of sightlines for studies of interstellar absorption. Such sightlines include those through dustier regions such as translucent clouds and long pathlengths through the Galactic halo and across adjacent spiral arms in the Galactic disk.

In this review, I will discuss recent optical and UV observations of interstellar absorption lines that are pushing these criteria to better understand molecular processes in diffuse clouds. Since this short discussion cannot do justice to all of the exciting work being done by the many investigators in this field, the reader is referred for more details to recent reviews by van Dishoeck (1992) on diffuse and translucent cloud chemistry, Herbig (1995) on diffuse interstellar bands, and Wilson & Rood (1994) and Savage & Sembach (1996) on interstellar abundances.

2. UV observations of diffuse clouds with *HST*

Most of the ground electronic state transitions of the atoms, ions, and molecules prevalent in diffuse clouds occur at ultraviolet wavelengths (912 to 3100 Å). Much of what we know about diffuse clouds has come from

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observations of these UV lines with the *Copernicus* and *International Ultraviolet Explorer* satellites (Cowie & Songaila 1986). With the launch of the *Hubble Space Telescope* (*HST*) in 1990, the Goddard High Resolution Spectrograph (GHRS) has brought new capabilities to these studies.

2.1. CAPABILITIES

The GHRS is capable of obtaining UV spectra with $R \approx 10^5$ and S/N ratios over 500 (Heap et al. 1995). However, much of the GHRS diffuse cloud work published in the literature has been done at $R \approx 2 \times 10^4$ due to problems with the far-UV echelle mode early in the *HST* mission. The major drawback of the GHRS is the limited wavelength coverage (6 to 15 Å) of its linear (512 pixel) Digicon detectors per echelle exposure. This drawback will be remedied during the 1997 *HST* servicing mission when the GHRS is replaced with the Space Telescope Imaging Spectrograph (STIS). Using two-dimensional MAMA detectors, this instrument will be able to obtain UV spectra with $R \approx 1.5 \times 10^5$ and about 200 Å wavelength coverage per echelle exposure. However, STIS may not be as sensitive as GHRS in detecting weak absorption lines due to expected difficulties in achieving S/N ratios greater than 100 with its MAMA detectors.

2.2. SEARCHES FOR NEW MOLECULAR SPECIES

Although only a few interstellar molecules have been identified in absorption at UV and optical wavelengths, their usefulness as probes of interstellar densities, temperatures, and radiation fields makes them indispensable to studies of diffuse clouds. This list of molecules includes the diatomic species H_2, CO, OH, NH, CH, CH^+, CN, and C_2 in various isotopic compositions. The size of this list not only reflects the simplified chemistry that occurs in diffuse clouds relative to dark clouds due to their lower densities and UV extinction but also the difficulty of detecting the weak absorption lines of trace molecular constituents. There are a number of molecules such as CH_2, HCl, H_2O, and NO^+ with transitions in the ultraviolet that would be promising candidates for searches in diffuse clouds with GHRS. Federman et al. (1995) have reported a 2.4σ detection ($W_\lambda = 0.57 \pm 0.24$ mÅ) of interstellar HCl C-X (0,0) R(0) λ1290 absorption in GHRS spectra of the star ζ Oph. If real, the strength of this feature is consistent with the HCl column density predicted by the van Dishoeck & Black (1986a) model of the ζ Oph cloud. Unfortunately, despite its sensitivity to weak lines, this HCl result is the closest that GHRS has come to detecting a new molecular species in a diffuse cloud. This rather poor showing is mostly due to the lack of a focused molecule search being awarded substantial amounts of scarce *HST* observing time as well as the limited GHRS wavelength coverage per echelle exposure. The much greater spectral coverage of STIS will make it a more efficient instrument to search for molecules but its poorer sensitivity to weak lines will not allow it to reach the low column density thresholds attainable with GHRS.

2.3. NEW UV VIEWS OF MOLECULES IN DIFFUSE CLOUDS

GHRS has been more successful at discovering new ways in which UV spectroscopy of known molecules can provide more sensitive diagnostics of the physical conditions in diffuse clouds. The following GHRS studies of molecules in the ζ Oph cloud are not only interesting in their own right, but also in the paths that they are establishing for further work in other sightlines.

2.3.1. *C_2*

Lambert, Sheffer & Federman (1995) have obtained GHRS observations of the interstellar C_2 D-X (0,0) and F-X (0,0) absorption bands at 2313 and 1342 Å toward ζ Oph. Their $R \approx 10^5$ spectrum of the D-X band clearly resolves the rotational structure and detects absorption from levels up through $J = 24$. The derived rotational populations are consistent with those determined from earlier near-IR observations of the C_2 Phillips bands (van Dishoeck & Black 1986b). The temperature ($T \approx 20 - 45$ K) and density ($n_H \approx 125 - 320$ cm^{-3}) implied by the GHRS observations agree with values suggested by other diagnostics of the ζ Oph cloud. These observations also provide the first accurate measurement of the relative oscillator strengths of the C_2 D-X, F-X, and Phillips systems.

2.3.2. *CO*

Through GHRS $R \approx 2 \times 10^4$ spectroscopy of ζ Oph, Federman et al. (1994) have detected seven weak intersystem transitions of interstellar ^{12}CO. The measured equivalent widths of these lines are approximately consistent with their predicted oscillator strengths and the ^{12}CO column density derived from the weakest of the observed A-X bands. With better laboratory measurements of their f-values, these optically thin intersystem transitions will make it possible to accurately determine the ^{12}CO column density in molecule-rich sightlines. One of the motivations in making such determinations is to better evaluate the ^{12}CO/^{13}CO ratio in diffuse clouds. Using the CO A-X bands, Lambert et al. (1994) have measured ^{12}CO/^{13}CO = 167 in the ζ Oph cloud with GHRS. They attribute this higher-than-expected value to fractionation through photodissociation where the more abundant ^{12}CO molecules are self-shielded to a greater extent.

2.3.3. H_2

In the same GHRS spectrum that reveals evidence of interstellar HCl, Federman et al. (1995) have detected the H_2 B-X (0,3) λ1275 band toward ζ Oph. This observation represents the first detection of UV absorption from vibrationally-excited H_2. The weakness of these lines suggests that the flux of UV radiation incident on the ζ Oph cloud is somewhat less than predicted at a level that is about 1 to 2 times the average interstellar radiation field. Federman (1996) is currently analyzing new GHRS observations of vibrationally-excited H_2 toward ρ Oph.

TABLE 1. Interstellar Gas-Phase Elemental Abundances

X	log $(X/H)^a_{Solar}$	log $(X/H)^b_{ISM}$	Reference
C	-3.45	-3.85	Cardelli et al. (1996)
N	-4.03	-4.15	Cardelli et al. (1996)
O	-3.13	-3.50	Meyer et al. (1996)
Mg	-4.42	-5.16	Sofia et al. (1994)
Si	-4.45	-4.80	Sofia et al. (1994)
S	-4.73	-4.71	Sofia et al. (1994)
Cr	-6.32	-7.76	Roth & Blades (1995)
Fe	-4.49	-5.56	Sofia et al. (1994)
Zn	-7.35	-7.54	Roth & Blades (1995)
Kr	-8.77	-9.01	Cardelli & Meyer (1996)

[a] Solar reference abundances for the CNO elements are the photospheric values from Grevesse & Noels (1993) and the remainder reflect the meteoritic values given by Anders & Grevesse (1989).
[b] These mean values reflect GHRS measurements of the interstellar gas-phase elemental abundances in the most tenuous diffuse clouds.

2.4. ELEMENTAL ABUNDANCES IN DIFFUSE CLOUDS

Since molecules are made out of atoms, the elemental abundances in diffuse clouds are an important parameter in their molecular chemistry. The high S/N capability of GHRS has made it possible to accurately measure the interstellar gas-phase abundances of a number of elements using very weak ($W_\lambda \approx 1$ mÅ) absorption lines. Table 1 summarizes some of this GHRS abundance work on chemically-interesting elements in diffuse clouds. For atoms like Fe and Cr that are heavily depleted from the gas phase into dust grains, the values quoted reflect mean gas-phase abundances in the most tenuous diffuse clouds. One of the most interesting aspects of this work is that it is now possible to evaluate the *total* (gas plus dust) interstellar

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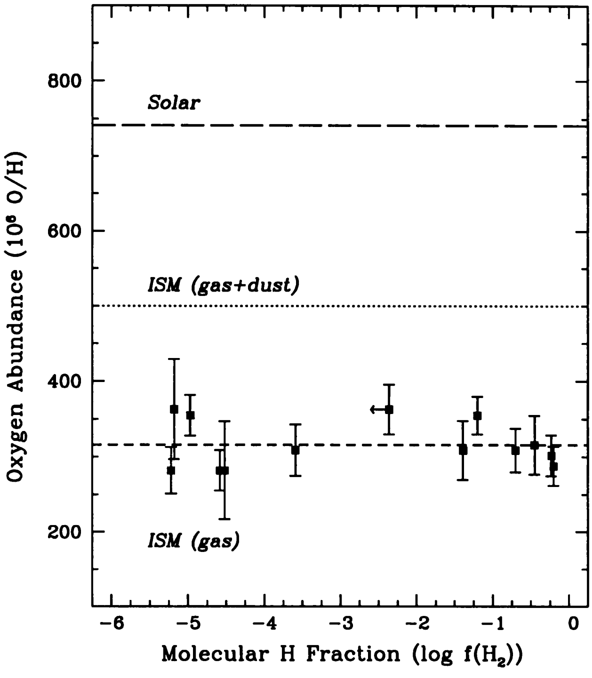

Figure 1. The interstellar oxygen abundances measured toward 13 stars with GHRS (Meyer, Jura & Cardelli 1996) as a function of the logarithmic fraction of hydrogen in molecular form, $f(H_2) = 2N(H_2)/[2N(H_2) + N(H\ I)]$, in the observed sightlines. The dashed line among the data points represents their weighted mean value (per 10^6 H atoms) of 10^6 O/H = 316 ± 9 for the interstellar gas-phase oxygen abundance. The dotted line near 10^6 O/H ≈ 500 represents the resulting *total* (gas plus dust) interstellar oxygen abundance after an allowance is made for the O tied up in dust grains. This value is about 2/3 of the solar oxygen abundance (10^6 O/H = 741 ± 130) (Grevesse & Noels 1993) denoted by the top-most dashed line in the figure.

abundances of some elements and critically compare them with the solar values.

2.4.1. *Oxygen*

Through GHRS observations of the weak O I] λ1356 intersystem line toward 13 stars, Meyer, Jura & Cardelli (1996) have determined a mean interstellar gas-phase oxygen abundance (per 10^6 H atoms) of 10^6 O/H = 316 ± 9. As seen in Figure 1, there are no statistically significant variations in the measured O abundances from sightline to sightline and no evidence of density-dependent depletion from the gas phase. In particular, using the fractional abundance of molecular hydrogen ($f(H_2) = 2N(H_2)/[2N(H_2) + N(H\ I)]$) as a barometer of gas/dust interactions, the mean O abundance in the 7 sightlines with log f(H_2) ≤ -2.0 (10^6 O/H = 318 $\pm$ 13) is essentially identical to that in the 6 sightlines with log f(H_2) ≥ -2.0 (10^6 O/H = 314 $\pm$ 12). Assuming various dust mixtures of oxides and silicates such as olivine, the abundance of interstellar O tied up in dust grains is unlikely to surpass 10^6 O/H $\approx$ 180 (Cardelli et al. 1996). It is difficult to further increase this O fraction in grain cores simply because the requisite metals are far less abundant than oxygen. Consequently, the GHRS observations imply that the *total* abundance of interstellar oxygen in the vicinity of the Sun is about 2/3 of the solar value of 10^6 O/H = 741 $\pm$ 130 (Grevesse & Noels 1993).

2.4.2. *Krypton*

Cardelli & Meyer (1996) have obtained GHRS observations of the Kr I λ1236 absorption toward 10 stars that yield a mean interstellar gas-phase krypton abundance (per 10^{12} H atoms) of 10^{12} Kr/H = 977 $\pm$ 23. As in the case of oxygen, there are no statistically significant variations in the measured Kr abundances from sightline to sightline and no evidence of density-dependent depletion from the gas phase. The latter is to be expected since, as a noble gas, Kr should not be depleted into dust grains at all. Consequently, the GHRS observations imply that the *total* abundance of interstellar krypton is about 60% of the solar value of 10^{12} Kr/H = 1698 $\pm$ 277 (Anders & Grevesse 1989). The fact that elements as nucleosynthetically distinct as O and Kr yield essentially the same interstellar abundance deficit with respect to the Sun suggests that the *cosmic* elemental abundances appropriate for the local ISM are below the solar values.

2.4.3. *Carbon*

Cardelli et al. (1996) have determined a mean interstellar gas-phase carbon abundance of 10^6 C/H = 140 $\pm$ 20 from GHRS observations of the very weak C II] λ2325 intersystem transition toward 6 stars. Like O and Kr, the measured C abundances are consistent within the errors in all of these sightlines and there is no evidence of density-dependent depletion from the gas phase. If, like oxygen, the *total* abundance of interstellar carbon is 2/3 of the solar value (10^6 C/H = 355 $\pm$ 43), the GHRS observations imply an amount of C in grains (10^6 C/H $\approx$ 100) that would tightly constrain extinction models. For example, this amount of solid carbon can explain such extinction features as the 2175 Å bump through graphite and/or PAHs but would put severe restrictions on the availability of carbon in grains to explain the total optical/UV dust opacity.

3. Optical observations of diffuse clouds

Except for a few transitions of CH, CH^+, and CN, the interstellar molecular lines observable from 3100 to 10,000 Å with ground-based telescopes are typically weak ($W_\lambda \leq 10$ mÅ) even through translucent clouds. However, optical instrumentation consisting of coude and echelle spectrographs and CCD detectors is now very well-equipped to detect interstellar absorption lines with equivalent widths less than 1 mÅ.

3.1. CAPABILITIES

The ability to perform very high resolution spectroscopy has been the most important development for interstellar work with optical instrumentation over the past few years. Such data have recently been obtained with the 0.9 m coude feed telescope ($R \approx 3 \times 10^5$) at Kitt Peak National Observatory (KPNO) (Meyer, Hawkins & Wright 1993), the coude spectrograph ($R \approx 5 \times 10^5$) on the McDonald Observatory 2.7 m telescope (Crane, Lambert & Sheffer 1995), and the Ultra High Resolution Facility (UHRF) ($R \approx 10^6$) on the 3.9 m Anglo-Australian Telescope (AAT) (Diego et al. 1995). In the case of detectors, the current generation of CCDs has high quantum efficiency ($QE \geq 60\%$) from 3100 Å in the near-UV to 9000 Å in the near-IR. Furthermore, Meyer (1990) has demonstrated that CCDs can produce net spectra with photon-noise-limited S/N ratios of 2000 or more with careful flat-fielding and summation techniques. The major limitation for current optical interstellar studies is measuring weak lines toward faint stars and this situation will soon improve as the high resolution spectrographs on the new 10 m class telescopes come up to speed. For example, the High Resolution Optical Spectrograph (HROS) on the Gemini South 8m telescope will be able to achieve $R \approx 1.5 \times 10^5$ and a S/N ratio of 100 on a $V = 12$ star in a 20 minute exposure.

3.2. SEARCH FOR INTERSTELLAR C_3

In an effort to search for new interstellar molecules at optical wavelengths, Haffner & Meyer (1995) have pushed the faintness limits of echelle spectroscopy on a 4m class telescope to examine the well-studied translucent sightline toward the star HD 147889 ($V = 7.89$; $E(B-V) = 1.09$) in the ρ Oph cloud complex. Over the course of four nights on the KPNO 4 m telescope, they obtained a 7 hour net exposure encompassing the C_3 A-X λ4050 spectral region at a resolution of $R \approx 2.5 \times 10^4$ and a S/N ratio of about 500. It is clear from this data that HD 147889 has been misidentified as a single rapidly-rotating B2 V star and is actually a double-lined spectroscopic binary consisting of two B2 IV-V stars with rotational (v sin *i*) velocities of about 30 and 70 km s^{-1}, an orbital period of about 5 days, and a radial velocity semiamplitude of about 70 km s^{-1}. Despite the potential confusion of shifting stellar lines, Haffner & Meyer have tentatively identified a $W_\lambda \approx 5$ mÅ interstellar feature at the wavelength (4051.6 Å) expected for an unresolved blend of the strongest Q-branch lines arising from the ground vibrational state of the C_3 A-X electronic transition. If real, the C_3 column density implied by the strength of this feature would be roughly consistent with models of the HD 147889 cloud (van Dishoeck & Black 1989).

3.3. OH IN DIFFUSE CLOUDS

Felenbok & Roueff (1996) have pushed the near-UV sensitivity of current ground-based instrumentation to observe the interstellar OH A-X λ3078 absorption band at $R \approx 1.2 \times 10^5$ toward the stars ζ Per and HD 27778 with the coude spectrograph on the 3.6 m CFH telescope. They detect several OH transitions in each sightline with measured line strengths down to sub-mÅ levels. Such a near-UV capability is important to exploit further since the interstellar NH A-X λ3358 band (Meyer & Roth 1991) is also found in this spectral region. A comparison of the OH and NH column densities in a number of sightlines would be very helpful in better establishing the respective roles of gas phase and grain surface chemistry in diffuse clouds. Unfortunately, interstellar OH absorption has still only been measured in 4 sightlines to date and NH even fewer with 2 detections.

3.4. VERY HIGH RESOLUTION CH, CH^+, AND CN SURVEYS

The interstellar CH A-X λ4300, CH^+ A-X λ4232, and CN B-X λ3875 lines have now been surveyed at very high resolution toward a number of stars by Crane, Lambert & Sheffer (1995) using the McDonald coude and Crawford (1995) using the AAT UHRF. These studies generally find no velocity differences between the CH and CH^+ absorption lines in a given sightline which provides a challenge for some shock models of CH^+ production. In cases where CH, CH^+, and CN are all observed in the same sightlines, the CN velocity components are typically narrower than the CH components which are typically narrower than the CH^+ components. Crawford has interpreted this behavior as being due to clumpy structure within the diffuse clouds where these molecules may not co-exist in the same absorbing regions.

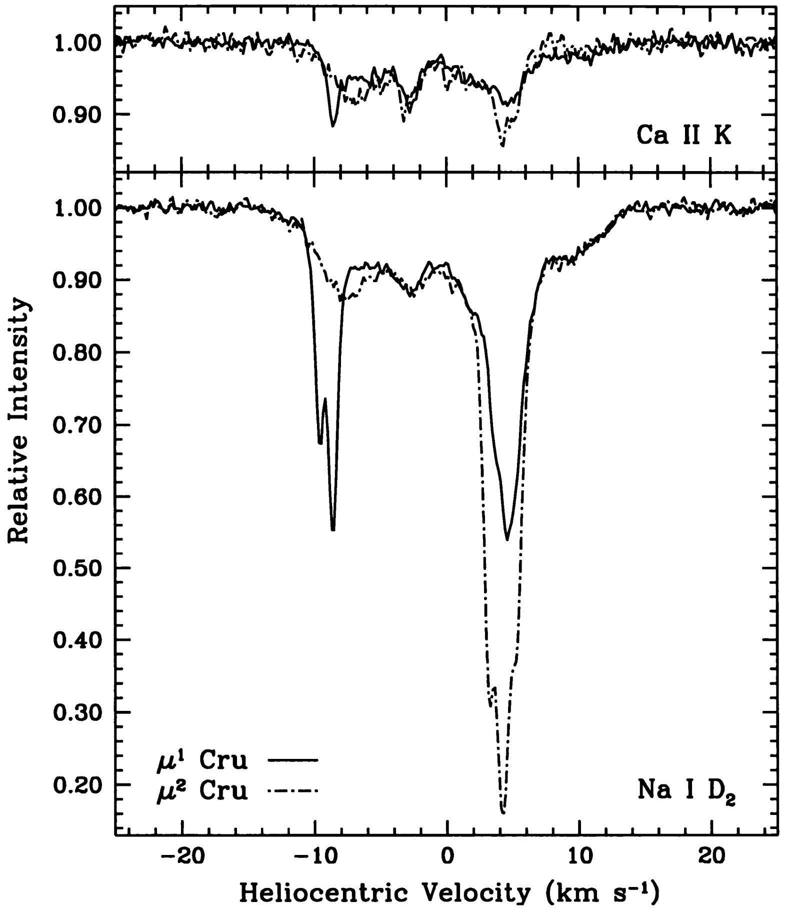

Figure 2. UHRF CCD spectra of the interstellar Ca II K and Na I D_2 absorption lines toward both members of the binary μ Cru displayed at an effective velocity resolution of 0.4 km s^{-1} (Meyer & Blades 1996). This binary consists of a B2 IV-V (V = 4.03) star (μ^1 Cru) and a B5 Ve (V = 5.17) star (μ^2 Cru) at an angular separation of 38.8″ that projects to 6600 AU (0.03 pc) at the binary distance of 170 pc. The obvious doublet character of the cold Na I feature at a heliocentric velocity of -8.6 km s^{-1} toward μ^1 Cru is due to the hyperfine splitting of the D lines.

3.5. SMALL-SCALE STRUCTURE IN DIFFUSE CLOUDS

The evidence for significant small-scale structure in diffuse interstellar clouds has been rapidly accumulating over the past few years. Following up on earlier VLBI studies of ISM structure at very small scales toward a few extragalactic objects (Dieter, Welch & Romney 1976; Diamond et al. 1989), Frail et al. (1994) have obtained multi-epoch observations of H I 21 cm absorption toward a sample of 7 high-velocity pulsars. They find evidence of significant ISM structure on scales ranging from 5 to 100 AU in all of these sightlines despite a wide variety in pulsar distances, directions, and 21 cm opacity.

Another approach to the question of small-scale ISM structure is through optical/UV observations of interstellar absorption lines toward both members of binary or common proper motion star systems. Meyer & Blades (1996) have recently obtained AAT UHRF observations of the interstellar Na I D_2 $\lambda5890$ and Ca II K $\lambda3934$ lines toward the binary μ Cru. As shown in Figure 2, among the 7 velocity components identifiable in the μ Cru Na I line profile, 4 exhibit line strength variations indicative of structure on scales less than the projected binary separation of 6600 AU (0.03 pc). The components with the greatest Na I column density variations have the narrowest line widths and the largest N(Na I)/N(Ca II) ratios. The N(Na I) excess of 2×10^{11} cm^{-2} in the most variable component corresponds to an N(H) excess of about 10^{20} cm^{-2}. This change in N(H) on a scale less than 6600 AU implies a density contrast of $n_H \geq 10^3$ cm^{-3}. In other words, this variation implies a molecular cloud density in a very diffuse sightline ($E(B-V) = 0.07$). Similarly high densities have been inferred for the Frail et al. (1994) cloudlets.

In an attempt to better determine the ubiquity of the Na I small-scale structure, Watson & Meyer (1996) have recently obtained high resolution KPNO coude feed observations of the Na I D absorption toward a sample of 17 binary stars. The binaries are scattered all over the sky at distances of 80 to 1300 pc and have projected separations ranging from 500 to 20,000 AU with most between 1000 and 3000 AU. The rather definitive result is that *all* of these binaries exhibit Na I absorption variations. Thus, in the cold diffuse gas sampled by Na I, small-scale structure appears to be quite common. Incorporating the density contrasts, length scales, and ubiquity of this structure in theoretical models is likely to have important implications for our understanding of molecular processes in diffuse clouds.

Acknowledgements

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References

Anders, E., Grevesse, N. 1989, Geochim. Cosmochim. Acta., 53, 197
Cardelli, J.A., Meyer, D.M. 1996, in preparation
Cardelli, J.A., Meyer, D.M., Jura, M., Savage, B.D. 1996, ApJ, 467, 334
Cowie, L.L., Songaila, A. 1986, ARAA, 24, 499
Crane, P., Lambert, D.L., Sheffer, Y. 1995, ApJS, 99, 107
Crawford, I.A. 1995, MNRAS, 277, 458
Diamond, P.J., Goss, W.M., Romney, J.D., Booth, R.S., Kalberla, P.M.W., Mebold, U. 1989, ApJ, 347, 302
Diego, F., et al. 1995, MNRAS, 272, 323
Dieter, N.H., Welch, W.J., Romney, J.D. 1976, ApJ, 206, L113
Federman, S.R. 1996, private communication
Federman, S.R., Cardelli, J.A., Sheffer, Y., Lambert, D.L., Morton, D.C. 1994, ApJ, 432, L139
Federman, S.R., Cardelli, J.A., van Dishoeck, E.F., Lambert, D.L., Black, J.H. 1995, ApJ, 445, 325
Felenbok, P., Roueff, E. 1996, ApJ, 465, L57
Frail, D.A., Weisberg, J.M., Cordes, J.M., Mathers, C. 1994, ApJ, 436, 144
Grevesse, N., Noels, A. 1993, in *Origin of the Elements*, ed. N. Prantzos, et al. (Cambridge University Press, Cambridge), p. 15
Haffner, L.M., Meyer, D.M. 1995, ApJ, 453, 450
Heap, S.R., et al. 1995, PASP, 107, 871
Herbig, G.H. 1995, ARAA, 33, 19
Lambert, D.L., Sheffer, Y., Federman, S.R. 1995, ApJ, 438, 740
Lambert, D.L., Sheffer, Y., Gilliland, R.L., Federman, S.R. 1994, ApJ, 420, 756
Meyer, D.M. 1990, in *CCDs in Astronomy*, ed. G.H. Jacoby (ASP, San Francisco), p. 345
Meyer, D.M., Blades, J.C. 1996, ApJ, 464, L179
Meyer, D.M., Hawkins, I., Wright, E.L. 1993, ApJ, 409, L61
Meyer, D.M., Jura, M., Cardelli, J.A. 1996, in preparation
Meyer, D.M., Roth, K.C. 1991, ApJ, 376, L49
Roth, K.C., Blades, J.C. 1995, ApJ, 445, L95
Savage, B.D., Sembach, K.R. 1996, ARAA, 34, 279
Sofia, U.J., Cardelli, J.A., Savage, B.D. 1994, ApJ, 430, 650
van Dishoeck, E.F. 1992, in *Astrochemistry of Cosmic Phenomena*, IAU Symposium 150, ed. P.D. Singh (Kluwer, Dordrecht), p. 143
van Dishoeck, E.F., Black, J.H. 1986a, ApJS, 62, 109
van Dishoeck, E.F., Black, J.H. 1986b, ApJ, 307, 332
van Dishoeck, E.F., Black, J.H. 1989, ApJ, 340, 273
Watson, J.K, Meyer, D.M. 1996, in preparation
Wilson, T.L., Rood, R.T. 1994, ARAA, 32, 191

Discussion

Avery: You discussed the small scale, high contrast structure seen in lines of sight towards binary pairs. What are the prospects of using similar nearby lines of sight to look for small scale variations in the DIB line strengths? Could you use such observations to infer what phase of the ISM produces the DIBs?

Meyer: We have observed several DIBs toward a few of our binary pairs. A preliminary analysis of two of these cases involving the DIB at 5780 Å does not reveal significant line strength differences. We plan on pursuing this avenue further in order to better determine if the DIB carrier(s) exhibits the same small-scale structure as Na I.

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Liszt: When discussing the spatial variability of optical absorption lines on an arcsecond or tens of arcseconds spatial scales it is important to compare with the previous $\sim$ 25 years results on H I absorption. Given this and the Frail et al. results on time-variability of H I against pulsars, why do you expect optical/UV absorption spectra to be time invariant?
Meyer: It may well be that the interstellar Na I absorption does vary over time in a particular sightline. This possiblility has not really been tested with data of the quality presented here. We plan to conduct such observations, especially on μ Cru, in the near future.

Wilson: The solar system has C and O abundances which are higher than the local ISM. Are there any exceptions to these results?
Meyer: To my knowledge, the most accurate absorption-line measurements of C and O in the local ISM are all consistent with abundances that are below the solar values.

Herbst: It might be interesting to extend your elemental abundance studies to higher extinction to look for depletions from the gas.
Meyer: We plan to study the C and O abundances in higher extinction sightlines after STIS is installed on HST.

Greenberg: I am pleased to report that the unified dust model which Li & Greenberg presented as a poster not only fits with your constraints on depletion of O and C, but also matches the *observed* average λ dependent extinction and polarization in diffuse clouds. It also confirms the fact that the available O:C ratio (after dust depletion) is greater than 1 by a significant amount. This has a strong influence on molecular cloud chemistry modelling.

Zare: Your high-resolution observations of the Na D lines are fascinating! Can you set any limits on the magnetic field effect (Zeeman effect) on causing the line shapes you report? What maintains the clumpiness of the clumps?
Meyer: Our resolution is not high enough to set any serious constraints on the magnetic field strength. However, it is certainly possible that magnetic effects could play an important role in maintaining the small-scale structures that we observe.

Flower: When discussing the kinematical evidence relating to CH and CH^+ in diffuse clouds, comparison should be made with the computed line profiles, integrated through the shock. In general, this is not done, and so conclusions regarding the feasibility of CH^+ formation in shocks may be premature.
Meyer: I agree, but the observed excellent agreement between the CH and CH^+ velocities may place constraints on some shock models.

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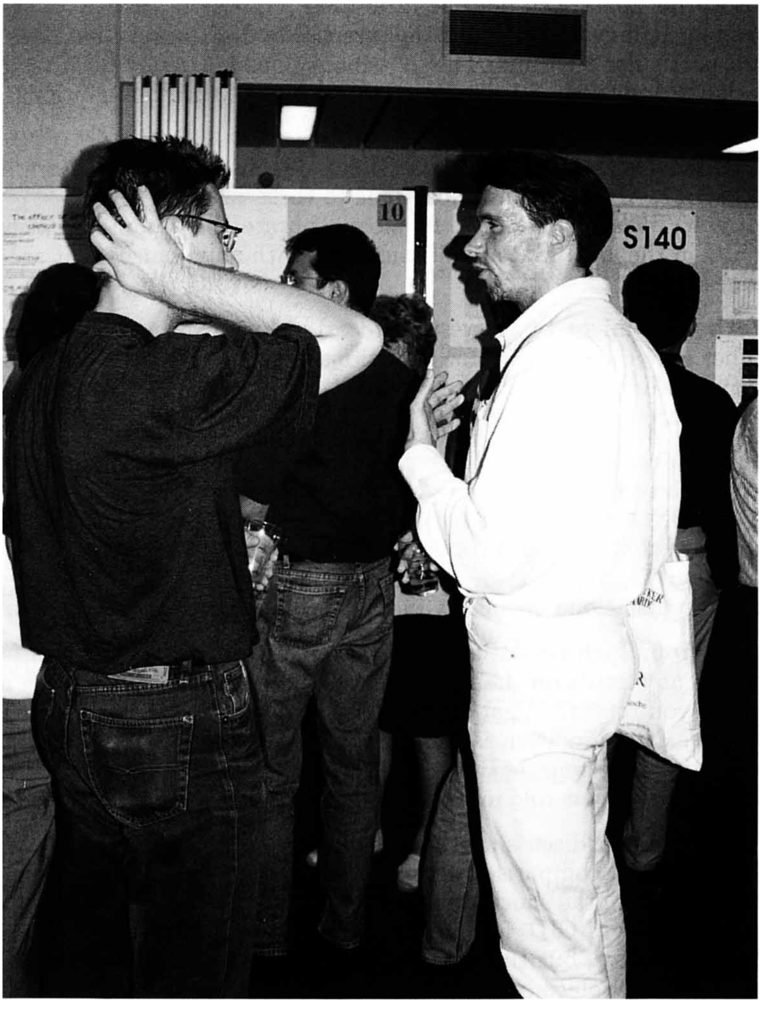

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