The Astrophysical Journal, 618:L99–L102, 2005 January 10

INTENSE DIFFUSE FAR-ULTRAVIOLET EMISSION FROM THE ORION NEBULA

Jayant Murthy
Indian Institute of Astrophysics, Koramangala, Bangalore 560 034, India; jmurthy@yahoo.com
and
David J. Sahnow and R. C. Henry
Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218; sahnow@pha.jhu.edu, henry@jhu.edu
Received 2004 October 17; accepted 2004 December 2; published 2004 December 16

ABSTRACT

We present spectra of the diffuse far-UV (900–1200 Å) emission from a region near the Orion Nebula: the first high-resolution spectra of the diffuse background radiation. These observations were made using serendipitous *Far Ultraviolet Spectroscopic Explorer* (*FUSE*) observations and were only possible because of the strength of the diffuse emission ($\approx 3 \times 10^5$ photons cm^{-2} sr^{-1} s^{-1} Å^{-1}) and the sensitivity of the *FUSE* instrument. Preliminary modeling suggests that the light is scattered starlight from the Trapezium stars, primarily θ^1 Ori C. However, a comparison of the spectra with nearby stars shows significant differences in the presence and strength of the absorption lines, particularly in the Lyβ line where there is much less interstellar absorption in our diffuse spectrum. We believe that we are indeed observing scattered light from the Trapezium stars but through a line of sight with much less matter than the direct line to the stars.

Subject heading: ISM: general

1. INTRODUCTION

The Orion Nebula (M42) is one of the best studied of all astronomical objects with emission in different wavelengths reflecting different aspects of its physics and morphology. An excellent description of the observations and the resulting model of the region is given by O'Dell (2001). Intense ultraviolet emission from the Orion Nebula has been observed by rocket flights (Bohlin et al. 1982; Tanaka et al. 1984) and from the *International Ultraviolet Explorer* (*IUE*; Mathis et al. 1981) and is presumed to be due to the forward scattering of the light of the brightest of the Trapezium stars—θ^1 Ori C (HD 37022)—by dust close to and in front of the star. Note that the scattering is not actually from the Orion Nebula, which is defined as a region of ionized gas in front of the Orion molecular cloud (OMC-1), but is rather from dust in the same direction. In this Letter, we present the first observations of diffuse emission from Orion in the far-ultraviolet (FUV) using serendipitous observations made by the *Far Ultraviolet Spectroscopic Explorer* (*FUSE*).

2. OBSERVATIONS AND DATA ANALYSIS

FUSE was launched on 1999 June 24 into a low Earth orbit by a Delta II rocket and has been observing astronomical targets since then. The spacecraft and mission have been described by Moos et al. (2000) and Sahnow et al. (2000). The instrument consists of four co-aligned optical channels, two of which are coated with silicon carbide (SiC) and two with lithium fluoride (LiF) over aluminum, providing coverage over the spectral range from 905 to 1187 Å. Diffuse sources, such as we report on here, will be visible in all three apertures (LWRS, MDRS, and HIRS), but useful spectra can only be obtained from the LWRS ($30'' \times 30''$) and, for sufficiently bright sources, MDRS ($4'' \times 20''$) apertures.

Two of the observations in the S405/505 program, an operational program used as part of the channel realignment of the *FUSE* spectrographs, were of a region of empty space near the star HD 36981 (Fig. 1, Table 1). A check of the attitude has shown that the actual pointing was within a few arcseconds of the nominal position. We have downloaded the data from these two observations and processed them using the standard CALFUSE pipeline (ver. 2.4; Dixon et al. 2002) with the modifications described by Murthy & Sahnow (2004). One of these modifications was to use only the data from the "NIGHT" part of the orbit in order to exclude all airglow emission, apart from the Lyman lines of atmospheric hydrogen. Although there may still be residual amounts of the O I lines around 1040 Å and the N I lines at 1134 Å (Feldman et al. 2001), these will not contribute to the intense continuum emission observed in Orion. Other modifications to the standard pipeline were that we added together all the different exposures that form a single observation and replaced the background subtraction procedure with one where we estimated the background from the region on either side of the aperture. Finally, in order to increase the signal-to-noise ratio, we binned together the spectra by a factor of 32 in wavelength, to reduce the effective resolution to about 700. We have used this procedure to reduce the data from most of the S405/S505 observations, and the results are discussed by Murthy & Sahnow (2004). This is the brightest of the diffuse fields observed in that program.

The resultant spectra are shown in Figure 2, in which we have co-added the data from the two different observations. There are three different spectra shown in the figure, all from the LWRS aperture: the co-added 1B and 2A SiC spectra (900–1000 Å), the 1A LiF spectrum (980–1100 Å), and the co-added 1B and 2A LiF spectra (1080–1200 Å). The same data are shown at higher resolution in Figures 3 and 4. For clarity, we have not shown the spectra from the other *FUSE* segments, which are entirely consistent with those plotted here. Because the diffuse emission is so bright, we were also able to extract spectra from the MDRS aperture, which was pointed about 3′ away from the LWRS. Despite the slightly different pointing, the MDRS spectra were essentially identical to the LWRS spectra.

3. RESULTS AND DISCUSSION

The *FUSE* spectrographs are the first instruments with sufficient sensitivity to perform absorption-line spectroscopy of the

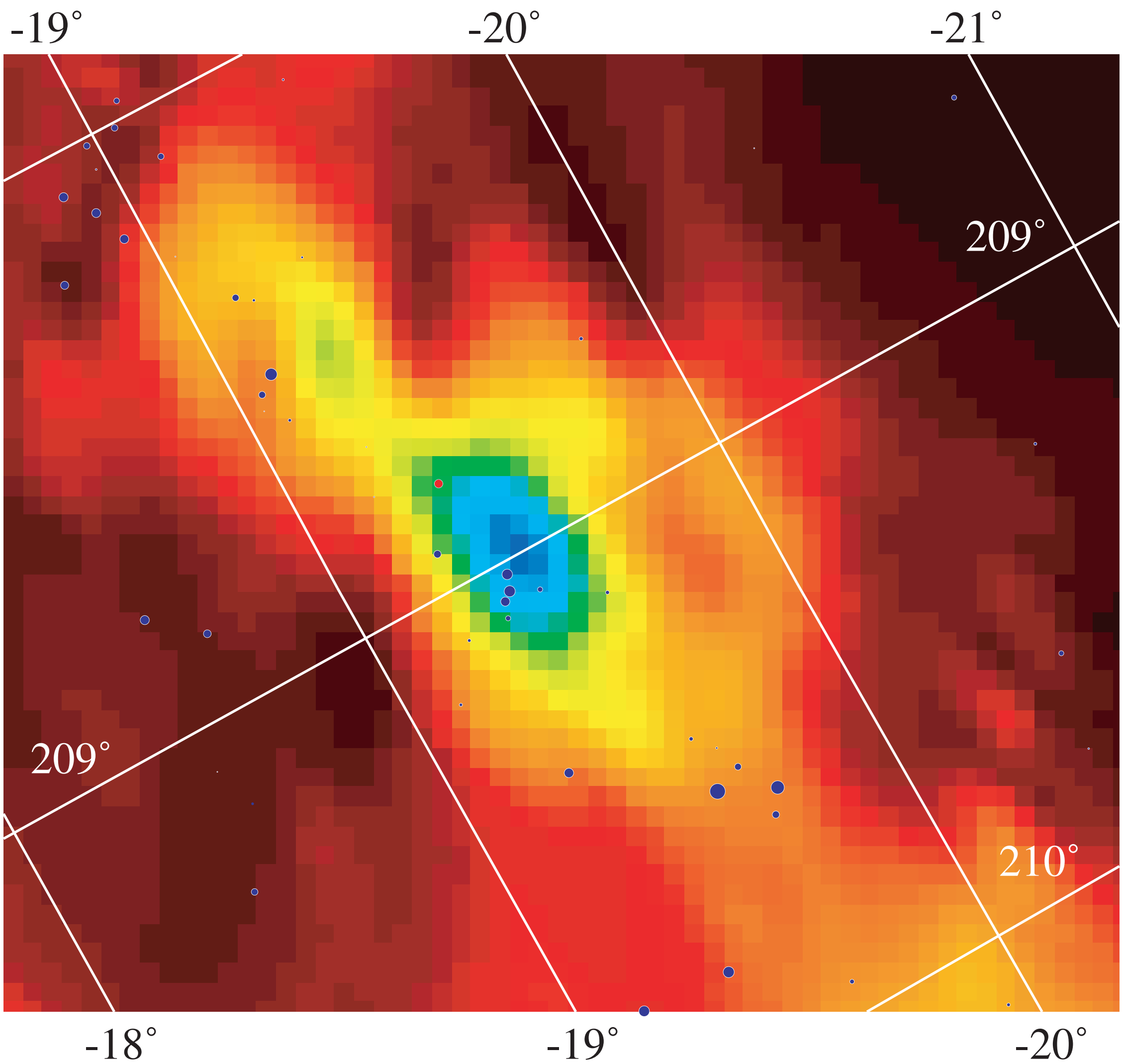

FIG. 1.—Interstellar dust map (Schlegel et al. 1998), with the Orion Nebula (M42) in the center of the image. Overplotted are the hot stars in Orion, with the size of the symbol proportional to the *TD-1* magnitude of the star. The two S40546 observations are very near the star HD 36981 (*red circle at the northeast edge of M42*). The LWRS (30″ × 30″) aperture is centered 105″ to the northeast of the star, and the MDRS aperture 100″ to the southwest. The observations are about 12′ away from θ^1 Ori C, which provides most of the power for the surrounding Orion Nebula.

diffuse interstellar medium, albeit only in bright areas such as Orion. The diffuse emission is due to scattered light from the nearby stars, and a comparison of the spectra can provide important clues about the source of the photons and the geometry of the dust. Although our first assumption was that we were observing scattering of the light of HD 36981 (B5 V, $V = 8$), only about 2′ away, a comparison of the spectra near Lyβ shows that HD 36981 cannot be the major contributor to the scattered radiation because the broad intrinsic Lyβ absorption in the star is not reflected in our observed spectrum (Fig. 3).

Despite its much greater distance (12′) from our observed locations, θ^1 Ori C (HD 37022; O5 V; $V = 5.1$)—the brightest of the Trapezium stars—may contribute as much or more energy as HD 36981, depending on the relative geometry. Unfortunately, HD 37022 is much too bright to observe with *FUSE* but was observed by *Copernicus*. We downloaded the spectrum from the Multimission Archive at the Space Telescope Science Institute (MAST) and applied the calibration of Snow & Jenkins (1977), and this is plotted in Figure 2. The shape matches the diffuse spectrum well until about 1150 Å, when interstellar Lyα absorption eats into the stellar spectrum. It was difficult to establish the absolute calibration of the *Copernicus* spectrograph, and instead we downloaded an *IUE* observation (SWP 5085) from MAST to compare the stellar flux with the diffuse spectrum, at least at wavelengths above 1150 Å (Fig. 4).

Despite the overall similarity in the shape of the spectra, a detailed comparison (Figs. 3 and 4) shows many differences. As with HD 36981, the Lyβ absorption line is much broader in the spectrum of θ^1 Ori C than in our diffuse spectrum but, in this case, is due to interstellar absorption in the several interstellar clouds in front of the Trapezium (Price et al. 2001). Many of the other features in the diffuse spectrum have been identified as lines of molecular hydrogen in both absorption and emission (K. France 2004, private communication; McCandliss 2003), which, surprisingly, do not appear with the same strength in

TABLE 1

OBSERVATIONAL PARAMETERS

Observation	Aperture	Night Exposure Time (s)	l (deg)	b (deg)
S4054601	LWRS	10565	208.81	−19.31
	MDRS	10565	208.81	−19.31
S4054602	LWRS	5696	208.82	−19.36
	MDRS	5696	208.81	−19.36

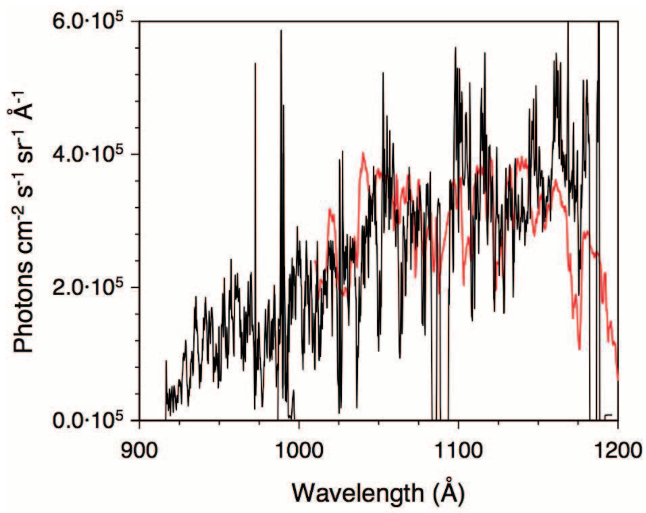

FIG. 2.—Spectrum for our diffuse observation. Only the spectra from three of the detector segments are shown for clarity; the extracted spectra from the other segments are consistent with these. Also omitted for clarity are the error bars, which are on the order of 10,000 photons cm^{-2} sr^{-1} s^{-1} Å^{-1}. Note the excellent agreement between segments at the edges, validating our empirical background subtraction procedure. Superposed on the plot is a scaled spectrum of θ^1 Ori (*red line*) taken from the *Copernicus* archive. The spectral shape is similar to the diffuse spectrum until the onset of interstellar Lyα absorption near 1200 Å.

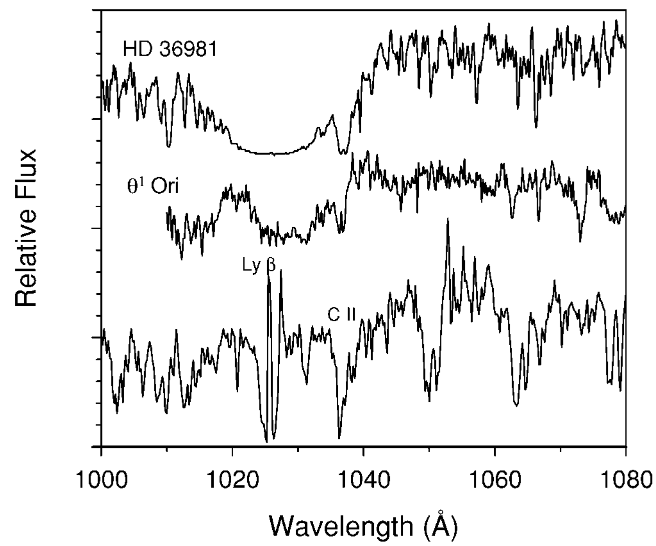

FIG. 3.—*From top to bottom*: The *FUSE* spectrum of HD 36981, the *Copernicus* spectrum of θ^1 Ori C, and the *FUSE* observation reported here. The Lyβ line is much broader in both stellar spectra than in the diffuse observation: in the case of HD 36981 because of self-absorption in the star and because of interstellar absorption in the case of θ^1 Ori C. The geocoronal Lyβ emission line is seen in the middle of the interstellar Lyβ (1026 Å) absorption line in our diffuse *FUSE* observation. Note that, surprisingly, the diffuse spectrum is rich in absorption lines that are not seen in either of the stellar spectra. K. France (2004, private communication) has suggested that these are largely due to H_2 absorption but also with contributions from fluorescent H_2 emission; however, a full analysis is beyond the scope of this work.

either of the stellar spectra, even though the stars are approximately colocated with the scattering dust.

While a definitive interpretation must await a more detailed analysis of the scattering geometry, it seems likely that we are observing the scattered light from θ^1 Ori C through a much lower column density line of sight than the direct line to the star. We have begun the process of modeling the entire spectrum including the absorption lines in order to determine the scattering properties of the dust grains near Orion.

4. CONCLUSIONS

We present the first high-resolution spectra of diffuse scattering in the FUV using serendipitous *FUSE* observations of a blank patch of sky near HD 36981 and just off the Orion Nebula. We propose that the emission is due to scattering of the light from θ^1 Ori C (12′ away) rather than the much closer HD 36981 (2′ away), based on a comparison of the spectra. The HD 36981 spectrum has broad self-absorbed Lyman absorption lines that are not seen in the diffuse spectrum. Although there are also broad Lyman absorption lines in the spectrum of θ^1 Ori C, these are due to interstellar absorption in foreground gas and suggest that the path traversed by the scattered photons includes much less gas than the direct path to the star.

We believe that such high-resolution observations of the diffuse scattering provide an important new tool for the study of interstellar dust scattering not just in understanding the spectral properties of the interstellar dust but also in providing clues to the origin of the diffuse emission. We have proposed new *FUSE* observations of several locations in and around M42 and hope to integrate these observations with archival *IUE* data in the region (for example, Mathis et al. 1981). Through these data and making use of the exceptionally well understood geometry around Orion, we should be able to, for the first time, pin down the optical properties of the interstellar dust grains from the FUV through the visible.

We thank the *FUSE* team for their support and quick response to the many questions we raised while working on this problem. In particular, Bill Blair, Van Dixon, Alex Fullerton, and B-G Andersson provided clarification on many points. Steve McCandliss and Kevin France pointed out the importance of H_2 absorption and emission in the diffuse spectrum. The data presented in this Letter were obtained from MAST. STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. Support for MAST for non–*Hubble Space Telescope* data is provided by the NASA Office of Space Science via grant NAG5-7584

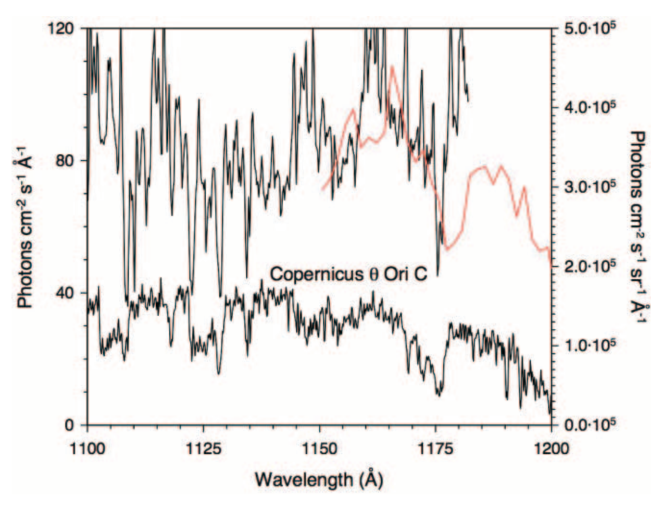

FIG. 4.—Our diffuse spectrum at long wavelengths with a calibrated *Copernicus* spectrum of θ^1 Ori C and the diffuse observation. Because of an uncertain calibration of the *Copernicus* data, we have also plotted an *IUE* observation of θ^1 Ori C that is well calibrated (*red line*). The units are photons cm^{-2} sr^{-1} s^{-1} for the stellar spectra on the left-hand side and photons cm^{-2} sr^{-1} s^{-1} Å^{-1} for the diffuse spectrum on the right-hand side.

and by other grants and contracts. This research has made use of NASA's Astrophysics Data System and the SIMBAD database, operated at CDS, Strasbourg, France.

REFERENCES

Bohlin, R. C., Hill, J. K., Stecher, T. P., & Witt, A. N. 1982, ApJ, 255, 87
Dixon, W. V. D., Kruk, J., & Murphy, E. 2002, The CalFUSE Pipeline Reference Guide (Ver. 1.3; Baltimore: Johns Hopkins Univ.), http://fuse.pha.jhu.edu/analysis/pipeline_reference.html
Feldman, P. D., Sahnow, D. J., Kruk, J. W., Murphy, E. M., & Moos, H. W. 2001, J. Geophys. Res., 106, 8119
Mathis, J. S., Perinotto, M., Patriarchi, P., & Shiffer, F. H. 1981, ApJ, 249, 99
McCandliss, S. R. 2003, PASP, 115, 651
Moos, H. W., et al. 2000, ApJ, 538, L1
Murthy, J., & Sahnow, D. J. 2004, ApJ, 615, 315
O'Dell, C. R. 2001, ARA&A, 39, 99
Price, R. J., Crawford, I. A., Barlow, M. J., & Howarth, I. D. 2001, MNRAS, 328, 555
Sahnow, D. J., et al. 2000, ApJ, 538, L7
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Snow, T. P., & Jenkins, E. B. 1977, ApJS, 33, 269
Tanaka, W., Onaka, T., Sawamura, M., Watanabe, T., Kodaira, K., & Nishi, K. 1984, ApJ, 280, 213