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The Diffuse Interstellar Bands
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λ4430 Emission by Comet Hyakutake

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Abstract. Comets provide a very different but well understood environment in which to search for DIBs. Observations of occultations by cometary comae have not detected DIBs, but none were very near the nucleus, where the column density of dust is highest. We report here unidentified emission bands, centered at λ4430, very near the nucleus of comet Hyakutake. These may be vaporized forms of grain carriers or fragments of large-molecule carriers. At least two different species appear to be present based on two different spatial distributions.

Keywords. comets, DIBs.

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1. Introduction

Recognizing the connection between cometary chemistry and interstellar chemistry, many people have considered searching for DIBs in comets. Several investigators have attempted to observe DIBs in absorption when a cometary coma passed in front of a bright star, but these have all been unsuccessful. See, e.g., Crawford & McNally (1987), Herbig (1990), Herbig & McNally (1999), and O'Malia *et al.* (2010). If the DIB carrier is a gas and follows the same correlation with CN in comets as in the ISM, DIBs should have been seen. However, none of the occultations was close enough to the nucleus to have sufficient attenuation by the dust in the coma to satisfy the correlation with A_V.

Compared to the interstellar medium, the cometary environment and its spatial variation are reasonably well understood. Thus further study of DIBs in comets is warranted. Given the cometary environment and the lack of knowledge of the DIB carrier, one might see the DIBs in absorption in an active comet with optically thick grains near the nucleus. Depending on the nature of the carrier, one might also find the carriers vaporized (collisionally controlled temperatures near 300 K at the nuclear surface dropping to 50K within 100 km due to adiabatic expansion), or one might find diagnostic fragments of the DIB carriers with the fragments being either photo-dissociated by solar ultraviolet radiation or thermally dissociated. Experience with other species suggests that solid-phase absorptions are sometimes coincident with the corresponding gas-phase emissions but at other times are shifted by up to the full width of the absorption. For example, the near-infrared (IR) absorption due to solid CO_2 is essentially coincident in location (4.2 μm) and width with the corresponding gaseous emission, whereas the near-IR absorption due to solid H_2O at 3.0 μm barely overlaps the gaseous emission that normally peaks at 2.8 μm. In this paper, we report serendipitous detection of unidentified emission features within the range of the λ4430 DIB and suggest that identification of this species might at least provide a clue to the nature of the DIB carrier.

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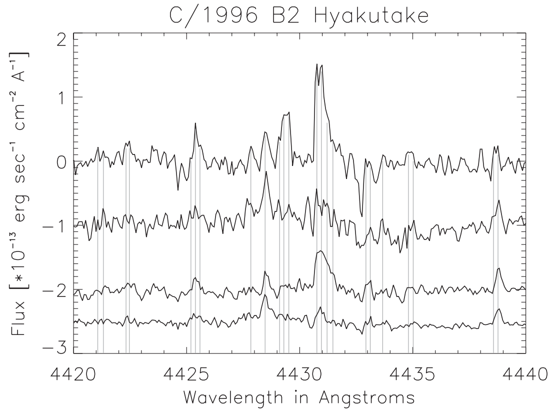

Figure 1. Spectra of C/Hyakutake with all emission lines marked by vertical lines. From the top, on-nucleus and offsets of 4, 6, and 10 arcsec (displaced below zero for clarity). Wavelengths are in air, corrected to the rest frame of the comet.

2. Observations

We observed comet Hyakutake (C/1996 B2) with the echelle spectrograph on the 4m Mayall Telescope at Kitt Peak National Observatory during a half night on 1996 March 26, the night of the comet's closest approach to Earth. Details of the observations were discussed by Meier *et al.* (1998) and by Kim *et al.* (2003). The spectra cover 3040-4500Å with a FWHM of roughly 0.18Å. Spectra were obtained centered on the nucleus and offset by approximately 4, 6, and 10 arcsec (310, 670, and 780 km). For all but one position, multiple exposures were combined in the spectra reported here. The projected slit was 68x580 km at the comet, oriented near (but not at) the parallactic angle initially but oriented E-W for most of the observations to improve efficiency. Differential refraction, with respect to the red-sensitive guide-camera, was less than the slit width at 4430Å.

Figure 1 shows a region of the spectrum encompassing the λ4430 DIB with spectra for all four slit positions shown. The spectrum at the photocenter (nominally the nucleus) is at top and successively lower plots correspond to positions successively further from the photocenter. Although very weak by comparison with well known cometary emissions at other wavelengths, these are the strongest emission features in the spectrum from longward of the strong CH A-X lines at 4290-4315Å to the end of the spectrum at 4500Å. Since there are no identified cometary features in this order of the echelle, the wavelength scale was set using the reflected solar absorption lines after correcting for the heliocentric radial velocity of the comet. A solar analog spectrum has been subtracted in order to show only emission features, and the spectrum displayed in the rest frame of the comet. Many of the emission lines are blended and we have used Gaussian ($\sigma \sim$ 0.09Å) decomposition to determine the wavelengths of the individual components. The corresponding wavenumbers in vacuum are given in Table 1 with arbitrary, sequential numbers assigned to each isolated feature, whether a single line or a blend.

3. Discussion

Clearly the emission lines do not all exhibit the same spatial profile, indicating that more than one species is involved. The single line in feature 5, at 4428.5Å, and the longer wavelength line in feature 11, at 4438.8Å, vary much more slowly with distance from the nucleus than do the other lines. These two lines likely correspond with the two strongest unidentified features, at λλ4428.46, 4438.59, in this portion of the spectrum of

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Table 1. Vacuum wavenumbers [cm^{-1}] of emission lines in spectra of C/Hyakutake

Feature ID	Emission Line 1	Emission Line 2	Emission Line 3	Emission Line 4
1	22625.3	22624.0		
2	22618.9	22618.1		
3	22604.2	22603.2	22602.2	
4	22590.7			
5	22587.5			
6	22584.2	22583.3	22582.1	
7	22575.8	22574.8	22573.5	22572.2
8	22564.8	22563.8		
9	22561.0			
10	22555.2	22554.1		
11	22536.1	22535.1		

122P/de Vico described by Cochran & Cochran (2002) and shown in their Figure 2. The complete list of emission lines in 122P/de Vico was published by Cochran *et al.* (2002). That spectrum was taken over a much larger field of view (870x5940 km) than ours, suggesting that these two features are from a species produced in the coma, whether by photo-dissociation or some other process, while the steep profiles of the other lines are consistent with a species that is either released from the nucleus or produced very close to the nucleus (within tens of seconds after release). Most emission lines in comets are produced by fluorescence, such that the surface brightness of the line maps the column density of the species. However, there are known cases of prompt emission, such as [O I], in which photo-dissociation produces a species in an excited state, which then spontaneously decays to the ground state. In this case, the surface brightness of the line tracks the column density of the parent molecule before the dissociation. In the absence of an identification of the species responsible for the emission lines, we cannot reliably assert that the steep-profile species are due to parent molecules rather than due to prompt emission of a fragment, but a parent molecule is the more likely situation.

We suggest that a concerted effort to identify the species observed in our spectrum might lead to useful insights into the nature of the DIB carriers.

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