A SEARCH FOR THE C\textsubscript{3} CARBON CLUSTER IN THE INTERSTELLAR MEDIUM

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ABSTRACT We have searched for rovibrational emission and absorption transitions arising from the 63 cm\textsuperscript{-1} v\textsubscript{2} (\pi\textsubscript{u}) bending vibration of the C\textsubscript{3} carbon cluster in the interstellar medium using the Betz/Boreiko heterodyne receiver on board the Kuiper Airborne Observatory. The Q(4) line at 1896.707 GHz was searched for in the IRc2 Orion/M42 and the W3 sources, and the R(2) transition at 1968.594 GHz was searched for in Sgr B2. No emission lines were observed in any source. However, a weak absorption was detected in Sgr B2 with a LSR velocity of 63.7±0.6 km s\textsuperscript{-1} and a FWHM linewidth of 7.9±0.8 km s\textsuperscript{-1}. This absorption is tentatively identified as the R(2) transition of the C\textsubscript{3} bending mode.

INTRODUCTION

A vital component of the NASA Astrophysics and Exobiology programs is to establish the form and distribution of carbon in the galaxy. The purpose of this goal is to address such diverse subjects as the fundamental physics and chemistry of circumstellar shells, interstellar clouds, and planetary atmospheres, as well as the role of interstellar carbonaceous material in the early evolution of life and the possibility of life elsewhere in the Universe. Several abundant forms of carbon are well studied in the interstellar medium, including CO, CI, and CII. In addition, a host of trace carbon-containing molecules, including the linear carbon chains HC\textsubscript{n}N, (n=1, 3, 5, 7, 9, 11), C\textsubscript{n}H (n=1-6), C\textsubscript{n}N (n=1-3), C\textsubscript{n}O (n=1, 3), and C\textsubscript{n}S (n=1-3) have been observed (Herbst 1990). Much of the interstellar dust is thought to be composed of carbonaceous material, including polycyclic aromatic hydrocarbons (PAH's). There is strong evidence to support the ubiquitous presence of pure (C\textsubscript{n}) carbon clusters in the interstellar medium. Optical emission from C\textsubscript{2} and C\textsubscript{3} was detected in comet tails (Weitner and Van Zee 1989), and mid-infrared absorption from C\textsubscript{3} (Hinkle et al.)
1988) and C$_5$ (Bernath et al. 1989) has been observed in the circumstellar dust surrounding the carbon star IRC+10216. The absence of a permanent dipole moment for these molecules precludes their detection in the cold interstellar medium by submillimeter astronomy. However, the linear forms of these clusters are known to possess low-frequency bending modes in the far-infrared region of the spectrum. We have proposed that these low-frequency bending modes may serve as the chromophores for detection of pure carbon clusters in the ISM by far-IR astronomy.

Over the last few years, the Saykally group has developed the technique of tunable far-infrared laser spectroscopy of jet-cooled clusters produced by laser vaporization (Figure 1), which is being used to perform precise measurements of the far-infrared bending frequencies of pure carbon clusters (Saykally 1993). The 63 cm$^{-1}$ $v_2$ ($\pi_u$) bending mode of C$_3$ has been characterized using this technique (Schmuttenmaer et al. 1990). Recently, the laboratory measurements of this C$_3$ bending mode were used to design a search for C$_3$ in the interstellar medium using the Betz/Boreiko heterodyne receiver (Betz and Zmuidzinas 1984) on board the KAO. A search for the Q(4) transition at 1896.707 GHz in the IRc2 Orion/M42 and W3 sources was performed during a KAO flight from the NASA Ames Research Center on January 28, 1994. The R(2) transition at 1688.594 GHz was searched for in the Sgr B2 source during the 1994 KAO Southern Skies Expedition #5 in New Zealand. No emission lines arising from these transitions were detected in any source. However, a weak absorption signal, which we have tentatively identified as the R(2) transition of C$_3$, was observed in Sgr B2. We are currently searching for the far-infrared bending frequencies of C$_6$-C$_9$ in the laboratory using the tunable far-infrared laser spectrometer. The bending transitions of these clusters are predicted to be lower in frequency than that of C$_3$, which may increase the probability of detecting emission lines from these larger clusters.

RESULTS AND DISCUSSION

The transition dipole of the $v_2$ bending mode of C$_3$ has been calculated to be 0.437 D (Jensen et al. 1991). From this we obtain an A-coefficient of about 7×10$^{-2}$ s$^{-1}$ for the dipole transition in the $v_2$ fundamental rovibrational band centered at 63.1 cm$^{-1}$. The critical density necessary to thermalize the $v_2$=1 level is thus estimated to be 2×10$^8$ cm$^{-3}$, assuming the temperature of the H$_2$ gas to be about 50 to 100 K. Such densities are observed only near the cores of dense molecular clouds. Therefore, emission signals arising from de-excitation of the $v_2$ mode should only be detectable in these regions. From the Betz/Boreiko receiver sensitivity, we have estimated that the minimum total column density required to detect these emissions is 3×10$^{14}$ cm$^{-2}$ for 100 K gas.

These constraints are relaxed somewhat when a source of continuum radiation at far-IR wavelengths is present, permitting molecular absorption lines to be observed. Such is the case in the HII star-forming region near the core of Sgr B2. Figure 2
Fig. 1. Schematic of the Berkeley tunable far-infrared spectrometer used in the laboratory determination of the \( v_2 \) bending mode of \( \text{C}_3 \). Tunable far-IR laser light is used to probe a supersonic expansion of vaporized graphite.

Fig. 2. Sgr B2 spectrum at the frequency of the R(2) transition of the \( \text{C}_3 \) bending mode. The smooth curve is a Gaussian profile fit to the data giving a peak amplitude of \(-1.2(2) \text{K}\) at 63.7(6) km/s and a FWHM linewidth of 7.9(8) km/s. The uncertainty per channel is 0.6 K after 84 min of integration. The numbers in parenthesis are uncertainties in the last digit.
displays the Sgr B2 spectrum that we observed at the wavelength of the R(2) line of the C₃ bending mode. Generally, detection of at least two transitions at the same LSR velocity is required to confirm the existence of a new molecule in an astrophysical source. Therefore, our assignment of the absorption line at 63.7±0.6 km s⁻¹ to C₃ is only tentative. However, the LSR velocity is characteristic of absorption lines from molecules in the gas near the core of Sgr B2 (Greaves et al. 1992) and is also consistent with other carbon chain molecules observed in this source (Turner 1971, Avery et al. 1976). A complete analysis of the Sgr B2 data is currently in progress and will be presented in a future paper.

It is curious that a C₃ absorption was not detected in the IRc2 region of Orion, since this is also a source of continuum far-IR radiation and since other carbon chain molecules have been detected in this region (Genzel and Stutzki 1989).

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REFERENCES