

A Search for Interstellar Carbon-60

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Abstract.

Carbon-60 has been proposed as a potentially important interstellar molecule. While there is a mounting body of indirect evidence suggesting that interstellar C₆₀ exists, no direct spectroscopic detection toward an astronomical object has been made. We present here the results of our search for interstellar C₆₀ in five sources using TEXES (the Texas Echelon Cross Echelle Spectrograph; Lacy et al. 2002).

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1. Introduction

The discovery of Buckminsterfullerene, C₆₀, by Kroto et al. (1985) launched a new branch of chemical research. It is sometimes forgotten that the impetus for the experimental discovery of “buckyballs” was an attempt to understand the formation of long-chain carbon molecules in interstellar and circumstellar material. The stability of the molecule was recognized immediately and led to the suggestion that C₆₀ may be widely distributed in the interstellar medium.

Currently, only indirect evidence exists for interstellar C₆₀. Because the ionization potential of C₆₀ is relatively low the majority of C₆₀ along optical/UV lines-of-sight will be ionized. Two electronic transitions of C₆₀⁺, observed in rare gas matrices, lie near two diffuse interstellar bands (DIBs) near 9600Å (Foing & Ehrenfreund 1997).

Detecting neutral C₆₀ may be easier toward an embedded source using infrared vibrational bands, such as the one near 1184 cm⁻¹ ($\lambda=8.45 \mu\text{m}$). The exact location and width of the band depends on the gas temperature. Assuming the average temperature is fairly low (T<100 K), the band structure should be fairly narrow, which argues for high spectral resolution.

2. Observations

We searched for the C₆₀ 1184 cm⁻¹ vibrational band in three high- extinction molecular cloud sources (AFGL 2136, AFGL 2591, NGC 7538 IRS 1), the mass-loss star NML Cygni, and R Corona Borealis. We used TEXES, the Texas Echelon-cross-Echelle Spectrograph, a high resolution, mid-IR spectrograph (Lacy et al. 2002) on the 3m NASA IRTF. In high

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resolution mode, TEXES provides resolving power $R=\lambda/\Delta\lambda \approx 100,000$ over a roughly 0.7% bandpass.

We first observed on 28 June, 2003. Depending on the brightness of the target, we spent between 5 minutes and 2 hours collecting data. We observed AFGL2591, NGC 7538 IRS1, and NML Cygni again on 15 Oct 2004. The second set of observations provide a separate Doppler shift to investigate the validity of weak features. We had a limited amount of time for these observations and spent between 5 and 30 minutes per target.

3. Data Reduction and Results

It was after performing a pipeline data reduction that we discovered our data contained significant fringing. We first tried to remove this fringing simply by dividing our source spectra by that of a telluric standard, but this approach failed to solve the problem. We proceeded to apply median and Butterworth lowpass filters, but these too failed to remove the fringing. Eventually we created a flattening procedure which fit a polynomial to the data. A fourth-order polynomial significantly decreased the fringing effects, and an eighth-order polynomial combined with dividing the target source by a telluric standard removed nearly all of the fringing. We recognize that such a high order polynomial may reduce our sensitivity to broad features, but should not preclude detection of narrow ones.

We ultimately achieved signal-to-noise ratios of 120-200 for the June 2003 targets. No absorption features are apparent. A 3% peak absorption (better than 3σ) in the R-head corresponds to a C_{60} column density of $3 \times 10^{15} \text{ cm}^{-2}$, assuming the temperature is on the order of 30 K. This suggests $< 0.6\%$ of interstellar carbon in the form of C_{60} . For comparison, the hypothesis that C_{60}^+ is a DIB carrier requires that 1% of carbon is in the form of C_{60}^+ .

There is concurrently a laboratory experiment underway at UIUC (in McCall's lab) to measure the precise band position and rotational constants of C_{60} in the gas phase using cavity ringdown laser absorption spectroscopy. The results of this experiment will greatly aid the determination of the appropriate limit set by the TEXES data. With a detection, the lab experiment would allow determination of the temperature of interstellar C_{60} by profile fitting.

4. Conclusions

Though we await the laboratory experiment results, there appears to be no clear detection of C_{60} in either of our observing runs. Our observations were sensitive to narrow features, and so a broad absorption line could remain undetected, especially after fitting a polynomial to the spectra. Nevertheless, even a non-detection could set a strong and meaningful constraint on the abundance of C_{60} and the viability of the hypothesis that C_{60}^+ is a DIB carrier.

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References

- Foing, B. H., & Ehrenfreund, P. 1997, *A&A* 317, L59
 Kroto, H. W., Heath, J. R., O'Brien, S. C., Curl, R. F., & Smalley, R. E. 1985, *Nature*, 318, 162
 Lacy, J. H., Richter, M. J., Greathouse, T. K., Jaffe, D. T., & Zhu, Q. 2002, *PASP* 114, 153