SEARCH FOR $\Delta$-DOUBLING TRANSITIONS OF SiH IN ORION KLEINMANN-LOW

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Received 2006 April 18; accepted 2006 June 20; published 2006 July 14

ABSTRACT

A recent submillimeter line survey of Orion KL claimed detection of SiH. This Letter reports on GBT observations of the 5.7 GHz $\Delta$-doubling transitions of SiH in Orion. Many recombination lines, including C164$\delta$, are seen, but SiH is not detected. The nondetection corresponds to an upper limit of $1.5 \times 10^{15}$ cm$^{-2}$ (4$\sigma$) for the beam-averaged column density of SiH. This suggests that the fractional abundance of SiH in the extended ridge is no more than twice that in the hot core.

Subject headings: ISM: individual (Orion Kleinmann-Low)—ISM: molecules—radio lines: ISM

1. INTRODUCTION

Interstellar hydrides are the building blocks of common molecules. In dense regions, unsaturated hydrides represent a critical intermediate step toward the formation of saturated hydrides as well as more complex oxygenated and nitrogenated molecules. For instance, SiO, SiN, SiS, SiC, and other molecules may be produced in large part due to gas-phase reactions with SiH (Turner & Dalgarno 1977; Mackay 1995). But despite the important role that simple hydrides play in astrochemistry, many have never been observed (van Dishoeck 1995). In the case of the SiH, this may be partly due to the fact that early estimates of the $\Delta$-doubling frequencies were highly uncertain. The $\Delta$-doubling frequency of 2940 MHz reported by Douglas & Elliot (1965) has a large (10%) uncertainty due to the extrapolation of results obtained experimentally at high rotational levels to low rotational levels. Approximate calculations by Wilson & Richards (1975) for the ground-state triplet at 3.0 GHz are in error by more than 150 MHz. More recent calculations by Brown et al. (1984,1985) give the transition frequencies to an accuracy of 3 MHz or $\sim$0.1%.

SiH (also known as silyldyne and silicon hydride) is iso-va!ent to the CH radical (methylide). The ground electronic state is $^2\Pi_{1/2}$, with a $\Delta$-doubling $J = 1/2$ transitions near 3000 MHz (e.g., Brown et al. 1985). This frequency is inaccessible from most present radio telescopes. However, the first-excited state ($^2\Pi_{3/2}$, $J = 3/2$), $\Delta$-doubling quartet is found at 5.7 GHz (Fig. 1), which is tunable at many radio telescopes.

In a recent submillimeter line survey of Orion KL, Schilke et al. (2001) report the first and only tentative detection of interstellar SiH. However, the six hyperfine $^2\Pi_{1/2}$, $J = 3/2 \rightarrow 1/2$ transitions are blended with strong emission from more common molecules (SO$_2$, CH$_3$CN, and CH$_3$OCH$_3$). Schilke et al. regard their detection as merely tentative and suggest that an interferometric follow-up may be required to determine whether the detected features are due to SiH.

This Letter reports on observations of the 5.7 GHz $\Delta$-doubling lines of SiH in order to attempt to confirm the Schilke et al. result in the centimeter-wavelength regime. Because the density of molecular line transitions at centimeter wavelengths is much lower than in the submillimeter, detection of the 5.7 GHz lines would conclusively demonstrate that SiH is indeed present in Orion KL. An additional motivation was the possibility of being able to determine the frequencies to much better accuracy than the 3 MHz obtained by the laboratory measurements of Brown et al. (1985).

2. OBSERVATIONS

Data were taken in nine sessions from 2006 February 2 to March 2 with the Robert C. Byrd Green Bank Telescope (GBT), operated by NRAO. The telescope was pointed at Orion KL ($\alpha = 05^h35^m14^s.5, \delta = -05^\circ22^\prime30^\prime$ [J2000]). The large beam (2/2 FWHM) encompasses nearly 150 K of continuum emission, precluding the use of position switching for calibration. Frequency switching with a switch frequency of 2 MHz was employed.

The GBT Spectrometer was used in 9-level mode to observe dual linear polarization in each of the four 12.5 MHz spectral windows centered at 5752.5, 5757.2, 5766.6, and 5771.4 MHz (the frequencies quoted by Brown et al. 1984,1985) in the radio frame $v_{LSR} = 4.7$ km s$^{-1}$, the velocity of the tentative SiH detection by Schilke et al. (2001). Each spectral window was divided into 8192 spectral channels, providing a channel separation of 1.526 kHz (0.08 km s$^{-1}$) before Hanning weighting. In addition, some data were taken with 50 MHz bandwidths using a switching frequency of 1 MHz.

Total time on-source was approximately 32 hr. A narrow interference feature near 5760.8 MHz was seen during the first 2 days of observations in the second spectral window. Channels containing this feature were flagged, as were the corresponding channels offset by $\pm$ 2 MHz. No other interference was noted.

Data reduction was performed in GBTIDL. A zeroth-order baseline was subtracted from the data. Spectral lines were fit with a Gaussian at the center frequency and two negative Gaussians constrained to be at the center frequency plus and minus the switch frequency with the same line width. The amplitude of the negative components was fit as a free parameter; in the limit wherein $T_{inc} \ll T_{sys}$, the amplitude of the negative components approaches $\sim 0.5$ times the amplitude of the positive component. In some intermediate frequencies (IFs), it was also necessary to fit a sinusoid to remove baseline ripples.

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\footnote{2 The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.}
Fig. 1.—Diagram of the ground state and first rotationally excited state of SiH. Schilke et al. (2001) claim a tentative detection of the two $^2\Pi_{1/2}$, $J = 3/2 \rightarrow 1/2$ triplets. Observations of the indicated $J = 3/2 \rightarrow 1/2$ doublings transitions are presented in this Letter. Frequencies are from Brown et al. (1985).

3. RESULTS

3.1. Recombination Lines

Figure 2 shows an overview of the spectrum of Orion KL around 5760 MHz based on 50 minutes of data using a 1 MHz switch frequency. The H104α recombination line dominates the spectrum, with a series of hydrogen recombination lines visible down to $\Delta n = 6$. He104α and C104α lines are also detected. Figure 3 contains an enlargement of the high-frequency data. The H149γ and H176ε features are clearly visible, and the He149γ line is detected as well.

The spectral region near 5752.5 MHz (SiH, $^2\Pi_{1/2}$, $J = 3/2$, $F = 1 \rightarrow 1$) is shown in Figure 4. Several recombination lines are seen, most prominently H164δ. Line fit parameters and line identifications are presented in Table 1. A two-component Gaussian fit is used for each of the H164δ and H187z lines. The lower frequency component of the H164δ line corresponds to a rather high velocity, but the line width suggests that this component is not molecular in origin. The lower frequency component of the H187z line is poorly determined, most likely due to blending with He164δ. The H213i line is also poorly fit due to its approximately 2 MHz offset from the H187z line; any error in fitting the latter will result in an incorrect fit of the former. The quality of these fits may also be affected by possible baseline errors associated with the lack of line-free channels in the frequency-switched spectrum. No features are seen in the spectral window centered at the other main line ($F = 2 \rightarrow 2$) frequency, 5771.4 MHz (Fig. 5).

The spectral region containing the frequencies of the $F = 1 \rightarrow 2$ and $2 \rightarrow 1$ lines is shown in Figure 6. The figure shows the combined data from two IFs, since neither IF spanned a large enough range of frequency to cover both the bright H104α line and its two negatives at plus and minus the switching frequency. The data from one IF have been scaled to produce a continuous spectrum in the region of overlap. In addition to the H104α line, He104α, C104α, and a heavier element 104α recombination line are seen. Small (∼1% of peak) fitting errors exist in the vicinity of the H104α line and its negatives, most likely due to the inadequacy of a two-component Gaussian model to fit the spectrum. Despite the overlap of the high-
Fig. 4.—Spectral region of $F = 1 \rightarrow 1$ and $1 \rightarrow 2$ lines. A 2 MHz switch frequency was used. The panels are the same as in Fig. 3. The blue lines indicate the calculated frequencies and ranges from Brown et al. (1985) as well as the expected signal from a beam-averaged column density of $1.5 \times 10^{15}$ cm$^{-2}$ (see § 3.3), vertically shifted for clarity.

frequency negative component with the other 104α recombination lines, the fits to the latter are not strongly affected owing to the clean negative version at 5767 MHz. It is possible that there are minor baseline ripples as well, but the paucity of line-free bandwidth in this region makes it difficult to determine the baseline structure to high accuracy.

![Graph of spectral region](image)

**TABLE 1**

| Frequency (MHz) | Line      | $v_{LSR}$ (km s$^{-1}$) | FWHM (km s$^{-1}$) | $T_A^*$ (K) |
|-----------------|-----------|-------------------------|--------------------|------------|
| 5751.678 ± 0.034 | H164α (?) | 24.7 ± 1.8              | 36.1 ± 2.2         | 0.06       |
| 5752.260 ± 0.005 | H164α     | −5.6 ± 0.3              | 32.9 ± 0.4         | 0.30       |
| 5754.836 ± 0.006 | C164α     | 9.7 ± 0.3               | 5.0 ± 0.9          | 0.02       |
| 5755.210 ± 0.238 | H187β     | 10.0 ± 12.4             | 46.6 ± 13.0        | 0.04       |
| 5755.678 ± 0.029 | H187β (?) | −14.4 ± 1.5             | 31.5 ± 2.9         | 0.07       |
| 5757.608 ± 0.020 | H213α (?) | −25.5 ± 1.1             | 46.0 ± 2.5         | 0.03       |
| 5762.902 ± 0.004 | H104α     | −1.1 ± 0.2              | 44.7 ± 0.4         | 0.62       |
| 5762.952 ± 0.001 | H104α     | −3.7 ± 0.0              | 26.8 ± 0.0         | 0.76       |
| 5765.319 ± 0.001 | He104α (?)| −4.7 ± 0.0              | 17.8 ± 0.1         | 0.91       |
| 5765.580 ± 0.001 | C104α     | 9.1 ± 0.0               | 4.7 ± 0.1          | 0.42       |
| 5765.709 ± 0.007 | S104α     | 10.9 ± 0.3              | 5.5 ± 0.8          | 0.05       |
| 5783.651 ± 0.010 | H176α     | −5.4 ± 0.5              | 34.4 ± 1.9         | 0.14       |
| 5788.588 ± 0.002 | H149γ     | −4.1 ± 0.1              | 44.7 ± 0.4         | 0.63       |
| 5791.098 ± 0.023 | He149γ (?)| −12.0 ± 1.2             | 29.6 ± 3.6         | 0.06       |

* Systematic errors are 10%–20%; random errors are usually significantly smaller.

b Poor fit; likely blended with He164α.

c Poorly constrained.

Fig. 5.—Spectral region of $F = 2 \rightarrow 2$ main line. Two sinusoidal ripples have been fitted. Some baseline structure remains, but no spectral lines are seen to within the noise limits. The top two panels are the same as in Fig. 4.

Fig. 6.—Spectral region of $F = 2 \rightarrow 1$ line. Small errors in fitting the H104α feature do not strongly affect the quality of fits of He104α and C104α. The panels are the same as in Fig. 4.
3.2. Comparison with Previous Work

Orion A is a complicated star-forming complex. Observations of other He lines find many broad components with LSR velocities between $-6$ and $+1$ km s$^{-1}$ within our beam (e.g., Pauls & Wilson 1977; Pankonin et al. 1979). The detected H104α profile likely contains contributions from each of these components.

The velocity and line width of the He104α line are in excellent agreement with values obtained for the He91α line by Natta et al. (1994). The parameters for the He149γ and He164δ lines are less well determined. The former is based on less than an hour of observing time, while the latter is blended with stronger emission from H187γ.

The C104α line is detected at $v_{\text{LSR}} = +9.1$ km s$^{-1}$, and the C164δ line is detected at $+9.7$ km s$^{-1}$, with line widths of around 5 km s$^{-1}$. This is the first detection in emission of a carbon δ line, although Stepkin et al. (2006) report on low-frequency carbon δ absorption. These parameters are in excellent agreement with other detections of carbon recombination lines in the Orion KL region (e.g., Balick et al. 1974; Ahmad 1976; Boughton 1978; Natta et al. 1994). In addition, the recombination line from a heavier element is detected. The line width of 5.5 ± 0.8 km s$^{-1}$ is consistent with the 3.5 ± 3.3 km s$^{-1}$ obtained by Ahmad (1976) in the 85α series, and the velocity shift of $-6.7$ ± 0.3 km s$^{-1}$ with respect to the C104α line is consistent with $-6.8$ ± 1.4 km s$^{-1}$ from Ahmad (1976). Based on expected element depletions, the most likely heavier element to produce a recombination line is sulfur (e.g., Pankonin et al. 1977; Qaiyum & Razaul lah Ansari 1983). The rest-frequency shift of SiH relative to C104α is $-8.5$ km s$^{-1}$, but it is not unreasonable to expect the sulfur line to be centered at a different velocity, due both to possible blending with other lines (such as Mg and Si) and to the fact that the sulfur and carbon trace slightly different (although overlapping) regions (Sternberg & Dalgarno 1995).

3.3. SiH

From the submillimeter data of Schilke et al. (2001), the FWHM line width of SiH is approximately 6 km s$^{-1}$, although the lines are blended with stronger features. Assuming that the A-doubling lines at 5.7 GHz have similar characteristics, the SiH lines would appear as narrow features (like carbon recombination lines) rather than broad features (like hydrogen recombination lines). The only narrow lines detected are identifiable as C104α, Si104α, and C164δ.

The strongest constraints on SiH abundance come from the main lines. The relative intensities of the four lines in local thermodynamic equilibrium are 5 : 1 : 1 : 9 for the 5752.5 ($F = 1 \rightarrow 1$), 5757.2 ($F = 2 \rightarrow 1$), 5766.6 ($F = 2 \rightarrow 1$), and 5771.4 MHz ($F = 2 \rightarrow 2$) transitions, respectively (Brown et al. 1985). Taking a dipole moment for SiH of 0.124 D (Lewerenz et al. 1983), the Einstein A-coefficient for the $F = 2 \rightarrow 2$ transition is $2.1 \times 10^{-12}$ s$^{-1}$. The nondetection of a feature in the 5771.4 MHz spectral window places a 4 σ limit on the strength of the line at 7.7 mK for a 6 km s$^{-1}$ FWHM line width in emission. (The $F = 1 \rightarrow 1$ main line is expected to be weaker and may be blended with the strong H164δ emission.) This places a beam-averaged upper limit of $1.5 \times 10^{-15}$ cm$^{-2}$ on the column density in the upper level. In this same level, Schilke et al. (2001) obtain an estimate of $4.2 \times 10^{-15}$ cm$^{-2}$ in a 12″ beam. Assuming that their detection is real, this suggests that the column density of SiH is enhanced by at least a factor of 3 in the hot core compared to the surrounding region.

The upper limit on the beam-averaged column density of SiH can also be used to deduce an upper limit of its enhancement in the hot core compared to the extended ridge, which fills approximately half the beam of the present observations (e.g., Ungerechts et al. 1997). The column density of H$_2$ in the hot core is approximately a factor of 3 higher than in the extended ridge (e.g., Blake et al. 1987). Thus, the fractional abundance of SiH in the ridge is no more than twice that in the hot core.

4. Conclusions

A search for the 5.7 GHz A-doubling lines of SiH in Orion KL did not yield a detection. The upper limit column density of $1.5 \times 10^{15}$ cm$^{-2}$ in the upper level suggests that the fractional abundance of SiH is not significantly higher in the extended ridge than in the hot core. Numerous recombination lines were detected, including several from helium, carbon, and possibly sulfur. Recombination line parameters are consistent with previous observations in the literature.

The author wishes to thank T. Minter for assistance in setting up the observations and for helpful advice on reducing the data, as well as D. A. Roshi for the reference regarding carbon δ detection.

Facilities: GBT

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