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Interstellar SiN

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Abstract. We report the detection of the silicon nitride (SiN) $N = 2–1$, $J = 5/2–3/2$ transition toward SgrB2(M), in absorption. Although it has been seen in a circumstellar envelope before, this is the first time this molecule has been detected in interstellar space. We estimate a column density of $(1-2)\times10^{13}$ cm^{-2}, which is a factor of 20−50 lower than that of silicon monoxide (SiO) toward this source. It is likely that this molecule, like SiO and FeO, is created by gas-phase chemistry after refractory elements, previously locked up in grain cores, have been released by sputtering in shocks.

Key words. astrochemistry – line: identification – ISM: abundances – ISM: molecules – ISM: individual objects: SgrB2(M) – radio lines: ISM

1. Introduction

Molecules containing refractory elements are exceedingly rare in the interstellar medium (see Walmsley et al. 2002, and references therein), since most such elements are condensed out into dust grains. The most widespread member of this class is the SiO molecule, which is only found in regions where energetic processes occur (outflows or PDRs, Richer et al. 2000; Schilke et al. 2001b). The only other silicon bearing molecules detected in the ISM so far are SiS (Dickinson & Rodriguez Kuiper 1981; Ziurys 1991) and SiH (Schilke et al. 2001a), but they have been little studied. SiO in flows, and most likely the other silicon bearing species as well, is assumed to be created through shock destruction of grain cores (Caselli et al. 1997; Schilke et al. 1997), which releases atomic silicon into the gas phase where it is rapidly converted into molecular form. Recently, another molecule containing a refractory element, FeO, has been detected (Walmsley et al. 2002); again the iron is believed to be released into the gas phase through shock destruction of grains cores.

Searches for other silicon bearing molecules in the ISM have been unsuccessful (e.g. SiN, Ziurys 1991), although these do exist in circumstellar envelopes (SiN, Turner 1992; SiC, Cernicharo et al. 1989; SiC_2, SiC_3, Apponi et al. 1999; Thaddeus et al. 1984; SiC_4, Ohishi et al. 1989; SIH_4, Goldhaber & Betz 1984; SICN, Guélin et al. 2000).

In this letter, we report the detection of interstellar SiN in absorption toward SgrB2(M). The electronic ground state of SiN is $^2\Sigma^+$, and it shows spin-rotation as well as magnetic- and electric-quadrupole hyperfine interactions, due to the quadrupole moment of ^{14}N. The transition frequencies have been measured by Saito et al. (1983). The observations were done toward SgrB2, which is is one of the most massive star forming cores in our Galaxy, having a total mass of $10^6\ M_\odot$. It also has a very massive envelope, in which many molecules are found in absorption. A very distinct characteristic is the existence of a thin ($N_{H_2} \geq 6\times10^{19}$ cm^{-2}), low density ($n_{H_2} = 10^3$ cm^{-3}), but very hot ($T_{kin} = 500\ K$) layer (Ceccarelli et al. 2002; Comito et al. 2003, and references therein), which is thought to be heated by shocks (Flower et al. 1995). This layer is responsible for a significant part of water absorption toward SgrB2 (Comito et al. 2003), but also is suspected of harboring other shock produced species (e.g. NH, Goicoechea et al. 2000; NH_2, van Dishoeck et al. 1993; FeO, Walmsley et al. 2002). The latter species, as well as SiO, are thought to be created by gas phase chemistry following a shock that destroyed grain cores by sputtering.

2. Observations

The observations toward SgrB2(M) α_{J2000} = 17:47:20.4, δ_{J2000} = −28:23:07 were performed at the IRAM 30 m telescope on Pico Veleta, on July 7, 2003. The weather conditions were excellent ($\tau_{225} \approx 0.1$ most of the time, corresponding to a precipitable water vapor content of ≈2 mm), and system temperatures at 87 GHz were 115 K (SSB). The receiver was tuned to SSB mode at the frequency of the $N = 2–1$, $J = 5/2–3/2$ line, centered on the strongest hyperfine component, $F = 7/2–5/2$ at 87 559.812 MHz, with an image rejection of −20 dB. The beam size of the 30 m telescope at this

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Table 1. Line parameters of the strongest hyperfine component (F = 7/2–5/2) of the SiN(N = 2–1, J = 5/2–3/2) line toward SgrB2(M). The fit was performed using the CLASS HFS method, i.e. fitting all HFS components simultaneously, but by enforcing an optically thin line. To convert into main beam brightness temperature, one has to multiply with the main beam continuum temperature, 2.6 K.

$\tau(N = 2–1, J = 5/2–3/2, F = 7/2–5/2)$	υ_{LSR}	$\Delta\upsilon$
	km s^{-1}	km s^{-1}
0.028 (0.005)	62.1 (0.2)	10.8 (0.6)

frequency is 29″. Pointing was checked on the continuum of SgrB2(M) itself, and is though to be good to about 3″. The VESPA autocorrelator was used, with two modules of bandwidths 640 and 160 MHz, and resolutions 320 and 40 kHz (1.1 and 0.15 km s^{-1}), respectively. In spite of the high image rejection, we checked the sideband assignment of our lines by changing the source velocity. No contamination from the other sideband was detected. We used the wobbler with a throw of 90″, which is sufficient to get off the continuum (e.g., Peng et al. 1995; Dowell et al. 1999) which, at 87 GHz, is dominated by free-free emission. We think the continuum level is reliable, and in the following display the line-to-continuum ratio. The integration time was 62 min on source. The other prominent core in SgrB2, SgrB2(N), was also observed, but not with sufficient signal-to-noise to either detect SiN, or give meaningful upper limits. An additional problem with SgrB2(N) is the very high emission line density, which corrupts the baseline and makes detections of weak lines difficult (see e.g. Nummelin et al. 1998).

3. Results

In Fig. 1 we show the spectrum containing the SiN line toward SgrB2(M). In this scale, the most prominent lines are absorption features of ethynyl (C_2H), but emission lines of isocyanic acid (HNCO) and methanimine (CH_2NH) are also seen. In Fig. 2 we zoom in to the spectrum of SiN(N = 2−1, J = 5/2−3/2) towards SgrB2(M), the fit results are shown in Table 1. Superimposed is a hyperfine fit, assuming optically thin lines. Only a linear baseline has been subtracted here, so the good match between observations and fit gives us confidence that we indeed have found SiN. Moreover, line velocity and width agree well with the values for ^{29}SiO determined by Peng et al. (1995) and de Vicente (1994).

In the following, we assume that the SiN molecule exists exclusively in the hot, shocked layer (see discussion below). Using the dipole moment determined by ab-initio calculations (Ziurys 1991) (2.3 Debye), the Einstein-A coefficient of the N = 2–1, J = 5/2–3/2, F = 7/2–5/2 transition of SiN is 2.6×10^{-5} s^{-1}, which translates, assuming a typical collision rate of 10^{-11} cm^{-3} s^{-1}, into a critical density of 2.6×10^{6} cm^{-3}. Since the actual density of the hot layer is in the 10^{3} cm^{-3} range, we can safely assume that the molecule is very subthermally excited, and in fact use an excitation temperature of 2.7 K. We note that, should the SiN molecule be distributed throughout the envelope, the derived column density would be a strict lower limit, which could underestimate the true column density by orders of magnitude (see discussion in Comito et al. 2003). Using the above assumptions, we calculate a total column density of $1.2(0.1) \times 10^{13}$ cm^{-2}, which would go to $2.1(0.1) \times 10^{13}$ cm^{-2} for an excitation temperature of 5 K. Observations of the optically thin ^{29}SiO(2–1) transition (de Vicente 1994; Peng et al. 1995) give an SiO column density of $>5 \times 10^{14}$ cm^{-2} toward SgrB2(M), so that the SiO/SiN column density ratio is in the range 20−40. The abundance of SiN relative to H nuclei, if the molecule is indeed restricted to the hot layer, is 1×10^{-7}, that of SiO is 4×10^{-6}.

The solar abundance of silicon is 3.6×10^{-5} (Anders & Grevesse 1989). Schilke et al. (1997) estimate that about 10% of the silicon in grain cores is released by the shock, and that about 10% of that goes into SiO, which means that one would expect an SiO abundance of 3.6×10^{-7}, which is about an order of magnitude below of which is observed. However, the calculations were done for a certain shock speed only, and the column density of the hot layer determined by Comito et al. (2003) is a lower limit, based on the assumption that all oxygen not locked up in CO is in water. Given all these uncertainties, we feel that the possibility that all silicon bearing species in the direction of SgrB2 are indeed produced in this hot layer cannot be excluded. Martín-Pintado et al. (2000) detect extended SiO in the Galactic center region, which they find to be correlated with X-ray excited Fe 6.4 keV line emission. It cannot be excluded that the hot layer in front of SgrB2 is just part of this very extended gas component heated by shocks and X-rays.

The chemistry of SiN has not gotten much attention, it has been examined in the framework of molecular clouds by only two papers, Roveri et al. (1988) and Mackay (1995). The major formation routes to SiN include

$$\mathrm{SiH + N \rightarrow SiN + H} \quad (1)$$

$$\mathrm{Si + NH \rightarrow SiN + H,} \quad (2)$$

it is destroyed by reactions with atomic nitrogen or oxygen or ionized carbon. No formation barriers are known.

Which of these reactions plays the main role depends on the abundances of the reaction partners. If silicon is released from grain cores, then it appears in atomic form, and reaction 2 will be dominant, if it exists in form of monosilane, SiH_4, on grain mantles, as advocated by Mackay (1995), reaction 1 will dominate. The evidence in general points to silicon being locked up in grain cores, because otherwise it would be much easier to release, and would appear more widespread than observed.

These observations show that, with the sensitivity of current instrumentation, many previously undetected molecules can be found. It appears worthwhile to retry many of the unsuccessful searches conducted in the 70s and 80s.

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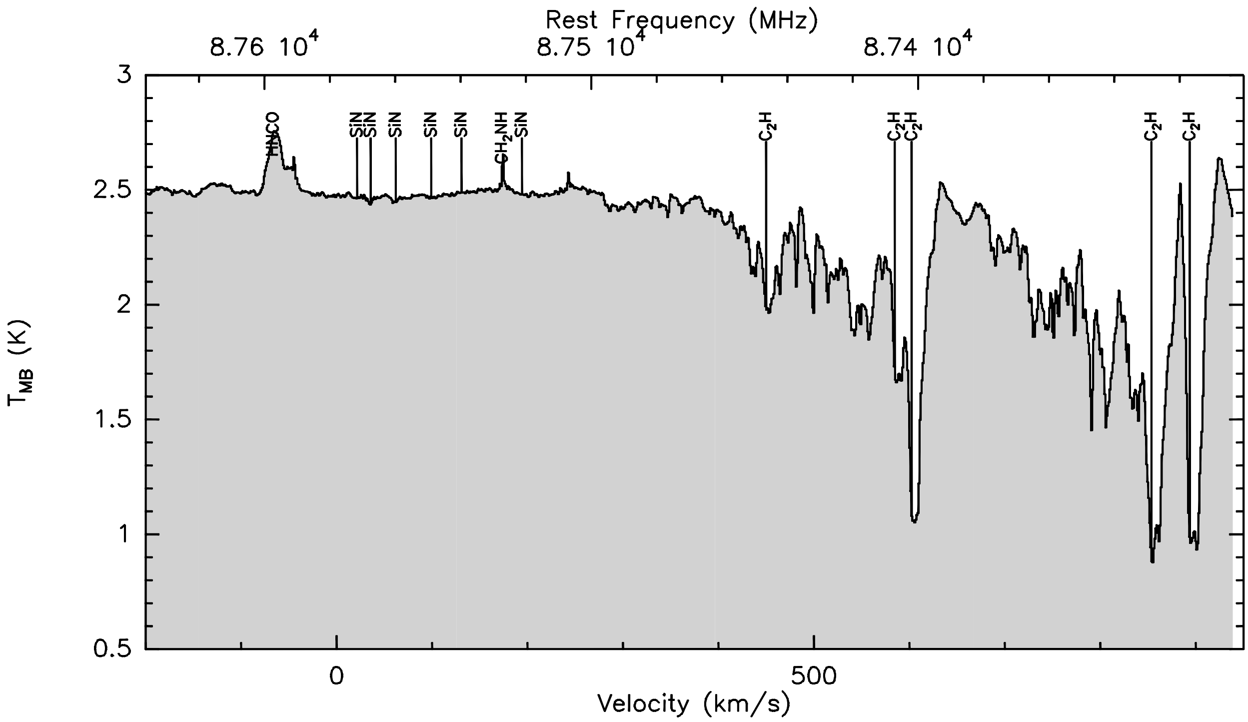

Fig. 1. Wide-band spectrum around the SiN line toward SgrB2.

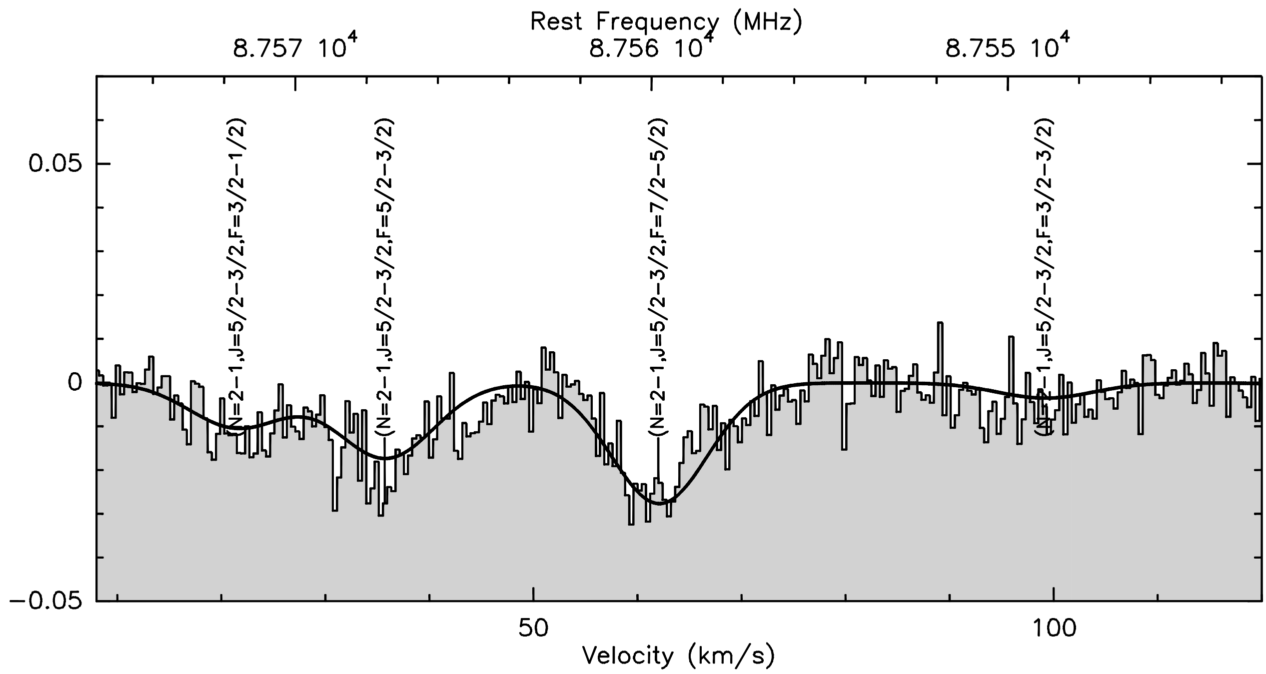

Fig. 2. SiN with optically thin hyperfine fitting toward SgrB2(M). The following frequencies, from the JPL catalog (For a discussion of the frequencies and errors see `http://spec.jpl.nasa.gov`) were used (in MHz): N=2–1, J=5/2–3/2, F=3/2–3/2: 87548.977(64), F=7/2–5/2: 87559.812(30), F=5/2–3/2: 87567.492(30), F=3/2–1/2: 87571.656(30).

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