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LETTER

Letter to the Editor

Search for LiH in the ISM towards B0218+357

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Abstract. We report a tentative detection with the IRAM 30m telescope of the LiH molecule in absorption in front of the lensed quasar B0218+357. We have searched for the $J = 0 \rightarrow 1$ rotational line of lithium hydride at 444 GHz (redshifted to 263 GHz). The line, if detected, is optically thin, very narrow, and corresponds to a column density of N(LiH) = 1.6 10^{12} cm^{-2} for an assumed excitation temperature of 15 K, or a relative abundance LiH/H_2 $\sim 3\,10^{-12}$. We discuss the implications of this result.

Key words: ISM: general, abundances, molecules – galaxies: ISM – quasars: absorption lines – radio lines: ISM

1. Introduction

Primordial molecules are thought to play a fundamental role in the early Universe, when stellar nucleosynthesis has not yet enriched the interstellar medium. After the decoupling of matter and radiation, the molecular radiative processes, and the formation of H_2, HD and LiH contribute significantly to the thermal evolution of the medium (e.g. Puy et al. 1993, Haiman, Rees & Loeb 1996). Even at the present time, it would be essential to detect such primordial molecules, to trace H_2 in the low-metallicity regions (e.g. Pfenniger & Combes 1994, Combes & Pfenniger 1997). Unfortunately, the first transition of HD is at very high frequency (2.7 THz), and the first LiH line, although only at 444 GHz, is not accessible from the ground at $z = 0$ due to H_2O atmospheric absorption. This has to wait the launching of a submillimeter satellite.

Although the Li abundance is low (10^{-10}–10^{-9}), the observation of the LiH molecule in the cold interstellar medium looks promising, because it has a large dipole moment, $\mu = 5.9$ Debye (Lawrence et al. 1963), and the first rotational level is at $\approx 21\,\mathrm{K}$ above the ground level, the corresponding wavelength is $0.67\,\mathrm{mm}$ (Pearson & Gordy 1969; Rothstein 1969). The line frequencies in the submillimeter and far-infrared domain have been recently determined with high precision in the laboratory (Plummer et al. 1984, Bellini et al. 1994). Because of the great astrophysical interest of this molecule (e.g. Puy et al. 1993), an attempt has been made to detect LiH at very high redshifts ($z \sim 200$) with the IRAM 30m telescope (de Bernardis et al. 1993). It has been proposed that the LiH molecules could smooth the primary CBR (Cosmic Background Radiation) anisotropies, due to resonant scattering, or create secondary anisotropies, and they could be the best way to detect primordial clouds as they turn-around from expansion (Maoli et al. 1996, but see also Stancil et al. 1996, Bougleux & Galli 1997).

There has recently been some controversy about the abundance of LiH. The computations of Lepp & Shull (1984) estimated the LiH/H_2 abundance ratio in primordial diffuse clouds to be as high as $10^{-6.5}$. With H_2/H $\sim 10^{-6}$, the primordial LiH/H ratio is $\sim 10^{-12.5}$. More recently, Stancil et al. (1996) computed an LiH/H abundance of $< 10^{-15}$ in the postrecombination epoch, since quantum mechanical computations now predict the rate coefficient for LiH formation through radiative association to be 3 orders of magnitude smaller than previously thought from semi-classical methods (Dalgarno et al. 1996). In very dense clouds, however, three-body association reactions must be taken into account, and a significant fraction of all lithium will turn into molecules. Complete conversion due to this process requires gas densities of the order $\sim 10^9$ cm^{-3}, rarely found in the general ISM. However, taken other processes into account, such as dust grain formation, an upper limit to the LiH abundance is the complete conversion of all Li into molecular form, with LiH/$H_2 \lesssim 10^{-10}$–10^{-9}. With a LiH column density of 10^{12} cm^{-2}, or N(H_2)= 10^{22} cm^{-2}, the optical depth of the LiH line will reach ~ 1, in cold clouds of velocity dispersion of $2\,\mathrm{km\,s^{-1}}$. The line should then be easily detectable in dense dark clouds in the present interstellar medium (like Orion where the column density reaches 10^{23}–10^{24} cm^{-2}). This is a fundamental step to understand the LiH molecule formation, in order to interpret future results on primordial clouds, although the primordial abundance of Li could be increased by about a factor 10 in stellar nucleosynthesis (e.g. Reeves 1994). Once the Li abundance is known as a function of redshift, it could be possible to derive its true primordial abundance, a key factor to test Big Bang nucleosynthesis (either homogeneous or not).

Up to now, due to atmospheric opacity, no astrophysical LiH line has been detected, and the abundance of LiH in the ISM is unknown. The atmosphere would allow to detect the isotopic

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molecule LiD (its fundamental rotational line is at 251 GHz), but it has not been seen because of the low D/H ratio, and the expected insufficient optical depth of LiH[1].

Another method to avoid atmospheric absorption lines is to observe a remote object, for which the lines are redshifted into an atmospheric window. Here we report about the first absorption search for a LiH line at high redshift: the latter allows us to overcome the earth atmosphere opacity, and thanks to the absorption technique we benefit of an excellent spatial resolution, equal to the angular size of the B0218+357 quasar core, of the order of 1 milli-arcsec (Patnaik et al. 1995). At the distance of the absorber (redshift $z = 0.68466$, giving an angular size distance of 1089 Mpc, for H_0=75 km/s/Mpc and q_0 =0.5), this corresponds to 5pc. We expect a detectable LiH signal, since the H_2 column density is estimated to be N(H_2)= 5×10^{23} cm^{-2}. Menten & Reid (1996) derive an N(H_2) value ten times lower than this, using the $H_2CO(2_{11} - 2_{12})$ transition at 8.6 GHz. At this low frequency the structure and extent of the background continuum source may be quite larger than at 100–200 GHz and the source covering factor smaller. This means that their estimate of the column density is a lower limit.

2. Observations

The observations were made with the IRAM 30m telescope at Pico Veleta near Granada, Spain. They were carried out in four observing runs, in December 1996, March, July and December 1997. Table 1 displays the observational parameters. We observed at 263 GHz with an SiS receiver tuned in single sideband (SSB). The SSB receiver temperature varied between 400 and 450 K, the system temperature was 600–1400 K depending on weather conditions, and the sideband rejection ratio was 10dB (the image frequency is at 271.5 GHz, in a region where the atmospheric opacity increases rapidly due to water vapour). We used a 512x1MHz filterbank and an autocorelator backend, with 0.3 km/s resolution. We present here only the 1MHz resolution spectra, smoothed to a 2.3 km/s channels, to improve the signal to noise.

The observations were done using a nutating subreflector with a $1'$ beamthrow in azimuth. We calibrated the temperature scale every 10 minutes by a chopper wheel on an ambient temperature load, and on liquid nitrogen. Pointing was checked on broadband continuum sources, and was accurate to $3''$ rms. The frequency tuning and sideband rejection ratios were checked by observing molecular lines towards Orion, DR21 and IRC+10216.

We integrated in total for 85 hours on the 263 GHz line, and obtained a noise rms level of 1.8 mK in the T_A^* antenna temperature scale, with a velocity resolution of 2.3 km/s. The forward and beam efficiencies at the observed frequency are displayed in Table 1. The continuum level was estimated by observing in a rapid on–off mode using a special continuum backend. The switch frequency of the subreflector was increased from 0.5 Hz to 2 Hz.

[1] the LiD line at 251 GHz is not covered in the 247–263 GHz survey of Orion by Blake et al. 1986, but was observed at the McDonald 5m-telescope, Texas, see Lovas 1992; we have ourselves checked with the SEST telescope that no line is detected towards Sagittarius-B2 at this frequency. The 3σ upper limit to the LiD abundance towards SgrB2 is 1×10^{11} cm^{-2}.

Table 1. Parameters for the tentative LiH line

J_u–J_l	1–0	
ν_{lab} GHz	443.953	
ν_{obs} GHz	263.527	
Forward eff.	0.86	
Beam eff.	0.32	
T_A^*	7 mK	depth of absorption line
$T_{\rm cont}$	15 mK	
FWHM	3.2 km/s	
σ	1.8 mK	noise rms with Δv 2.3 km/s

α(1950) = 02h 18m 04.1s
δ(1950) = $35^\circ\ 42'\ 32''$

3. The molecular asborption line system towards B0218+357

We select the ISM in front of the B0218+357 BL Lac object, because it revealed the highest molecular column densities in all cases of molecular absorption at high redshift (Wiklind & Combes 1995, Combes & Wiklind 1996). The remote quasar is gravitationally lensed by a foreground galaxy at z=0.68466, which produces the absorption. The radio image of the quasar is composed of two distinct flat-spectrum cores (A and B component), with a small Einstein ring surrounding the B image, of 335 milli-arcsecond (mas) in diameter (Patnaik et al. 1993). Since the ring has a steeper spectrum, it is interpreted as the image of a jet component, or in fact a hot spot or knot in the jet that happens to be just in the line of sight of the lens center.

The intensity ratio between the two images is A/B $\approx$ 3.3 at several radio wavelengths, and it can vary slightly (the B-component has varied in flux by $\approx$ 10% in a few months, O'Dea et al. 1992, Patnaik et al. 1993). A large variety of molecules has been detected in absorption towards B0218+357, among them several of the isotopes of CO, HCN, HCO^+, HNC, H_2O etc.. (Wiklind & Combes 1995, Combes & Wiklind 1995, 1997). Since the depth of the molecular absorption is less than the continuum level, while being optically thick, we deduced that the absorbing material does not cover the whole surface of the continuum. This has been directly checked through high-resolution interferometry (Menten & Reid 1996, Wiklind & Combes 1998). Only the A image is covered by molecular clouds, and the fraction of the total continuum which is absorbed is $\sim$70%.

Using the Jet Propulsion Laboratory catalog of molecular transitions (Poynter & Pickett 1985), we have checked whether the observed absorption line could be caused by another molecule. This was done for both signal and image frequencies (263.5 GHz and 271.5 GHz) and for z=0 and 0.68466. At z=0, we have also looked for absorption of Galactic molecular gas

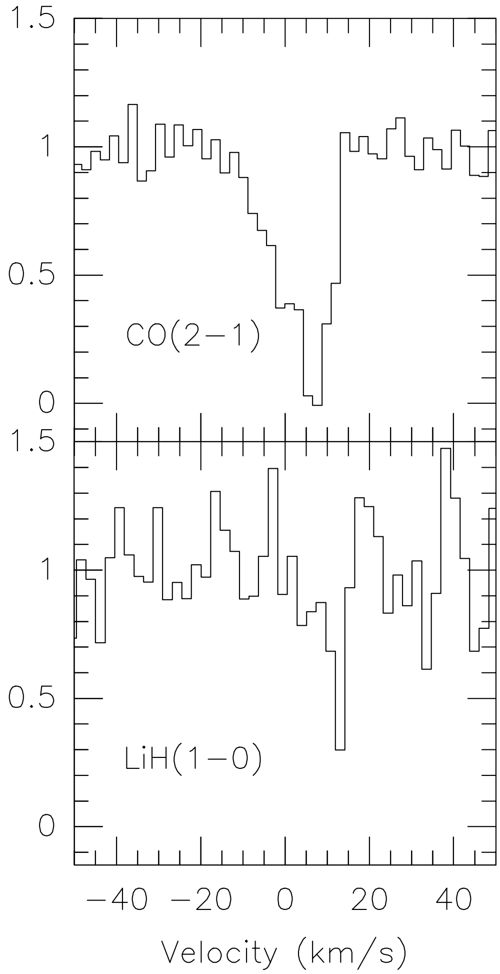

Fig. 1. Spectrum of LiH in its fundamental line (1–0) at 444 GHz, redshifted at 263 GHz, in absorption towards B0218+357, compared to the highly optically thick CO(2–1) line previously detected. The tentative LiH line is slightly shifted from the center by about 5 km/s, but is still comprised within the CO(2–1) velocity range. Its width is compatible with what is expected from an optically thin line. Spectra have been normalised to the absorbed continuum level and the velocity resolution is 2.3 km/s

using the HCO^+(1–0) line at 89 GHz, without seeing any hint of absorption.

4. Results and discussion

Fig. 1 presents our LiH spectrum, compared to that of CO(2–1) previously detected with the IRAM 30m-telescope (Wiklind & Combes 1995, Combes & Wiklind 1995). There is only a tentative detection of LiH at $\sim 3\sigma$. The line is very narrow, but is compatible to what is expected from an optically thin line. The CO(2–1) is highly optically thick, with $\tau \sim 1500$. This optical depth is determined from the detection of $C^{18}O$(2–1), which is moderately thick, and the non–detection of $C^{17}O$(2–1). The center of the tentative line is shifted by 5 km/s from the average center of other lines detected towards B0218+357. This shift cannot be attributed to uncertainties of the line frequency, since it has been measured in the laboratory (e.g. Bellini et al. 1994), and the error is at most 0.24 km/s at 3σ, once redshifted. But the scatter of the line centers is ~ 3 km/s, and the width of most of the lines is ~ 15 km/s (cf Wiklind & Combes 1998). The velocity shift is therefore insufficient to reject the line as real.

Table 2. Derived LiH column density

T_x	(K)	5	10	15	20
N(LiH)	(10^{12} cm^{-2})	0.4	0.9	1.6	2.4
LiH/H_2	(10^{-12})	0.8	1.8	3.2	5

Combining our own continuum data with that of lower frequencies (obtained from the NASA Extragalactic Database NED), we have previously found that the continuum spectra of B0218+357 can be fitted with a power law of slope -0.25 (Combes & Wiklind 1997). This would imply a continuum level of 15.5 mK at 263 GHz, which is in accord with the measured level. Since only 70% of the continuum is covered by molecular gas, the continuum level to be used for our LiH observations amounts to 11 mK.

We can write the general formula, concerning the total column density of the LiH molecule, observed in absorption between the levels $l \rightarrow u$ with an optical depth τ at the center of the observed line of width Δv at half-power:

$$N_{LiH} = \frac{8\pi}{c^3} f(T_x) \frac{\nu^3 \tau \Delta v}{g_u A_u}$$

where ν is the frequency of the transition, g_u the statistical weight of the upper level ($= 2J_u{+}1$), A_u the Einstein coefficient of the transition, T_x the excitation temperature, and

$$f(T_x) = \frac{Q(T_x) exp(E_l/kT_x)}{1 - exp(-h\nu/kT_x)}$$

where $Q(T_x)$ is the partition function. For the sake of simplicity, we adopt the hypothesis of restricted Thermodynamical Equilibrium conditions, i.e. that the excitation temperature is the same for all the LiH ladder. Since the line is not optically thick, but the optical thickness reaches τ = 1.3 at the center of the line, we have derived directly from the spectrum, through a Gaussian fit of the opacity, the integrated $\tau\Delta v$ = 3.64 km/s. From the formulae above, and assuming an excitation temperature of T_x = 15 K (see Table 2 for variation of this quantity), we derive a total LiH column density of 1.6 10^{12} cm^{-2} towards B0218+357. Compared to our previously derived H_2 column density of 5 10^{23} cm^{-2}, this gives a relative abundance of LiH/H_2 $\sim 3\,10^{-12}$. Note that there is a possible systematic uncertainty associated with this measure, due to the velocity difference between the maximum opacity of the CO, HCO^+ and other lines with that of LiH.

To interpret this result, comparison should be made with the atomic species. First, it is likely that the molecular cloud on the line of sight is dense and dark, and all the hydrogen is molecular, f(H_2) = 0.5. The Li abundance (main isotope ^{7}Li) at $z = 0.68466$ (i.e 5–10 Gyr ago) can be estimated at Li/H $\sim 10^{-9}$, since its abundance in the ISM increases with time.

The primordial Li abundance must be similar to that in metal deficient unevolved Population II stars, Li/H = 1–2 10^{-10} (Spite & Spite 1982), but Li could be depleted at the stellar surface by internal mixing. In meteorites and unevolved, unmixed Pop I stars, Li/H $\sim 10^{-9}$, representative of the Li abundance some 4 Gyr ago. The present abundance in the ISM is estimated around 3 10^{-9} (Lemoine et al. 1993).

We therefore deduce LiH/Li $\sim 1.5\,10^{-3}$. The uncertainty associated with the derived abundances are large, but the low LiH/Li ratio seems to exclude complete transformation of Li into LiH, as would be expected in very dense clouds (e.g. Stancil et al. 1996, although the Li chemistry is not yet completely understood in dark clouds). However, it is likely that the cloud is clumpy, and in some of the more diffuse parts, LiH is photodissociated (e.g. Kirby & Dalgarno 1978). Also, some regions of the cloud could have a higher excitation temperature, in which case our computation under-estimates the LiH abundance (although the absorption technique selects preferentially cold gas, and the black-body temperature at the redshift of the absorbing molecules is T_{bg} = 4.6 K).

The present observations suggest that the detection of LiH in emission towards dense clouds in the Milky Way should be easy with a submillimeter satellite, provided that the spatial resolution is enough to avoid dilution of the dense clumps. It is also interesting to observe the rarer molecule ^{6}LiH, which in some clouds might be of same order of abundance as the main isotopic species. Through optical absorption lines Lemoine et al. (1995) find towards two velocity components in ζ-Oph, ^{7}Li/^{6}Li = 8.6 and 1.4. Since ^{6}Li is formed only in negligible amounts in the Big Bang, this ratio indicates that cosmic ray spallation has increased significantly the Li abundances.

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