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Search for glycine in the solar type protostar IRAS 16293-2422

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Abstract. We report the first search for line emission from one of the simplest amino acids, glycine, from a solar type protostar, IRAS16293-2422. Previous searches for glycine have been carried out on bright massive star formation regions, so far without success. Recent observations show that although less luminous, solar type protostars also harbor complex molecules and may even be more favorable than massive protostars for the formation and survival of complex molecules.

We did not detect any emission associated with glycine from IRAS16293-2422. Based on these observations, we claim that the glycine column density is less than $\sim 5 \times 10^{12}$ cm^{-2}. Using information we have on the structure of the envelope surrounding IRAS16293-2422, we derive an upper limit to the glycine abundance of $\sim 1 \times 10^{-10}$ in the cold outer envelope and $\sim 7 \times 10^{-9}$ in the hot core, respectively. These observations challenge recent theoretical estimates of glycine abundance in solar type protostars.

Key words: stars: formation – ISM: abundances – ISM: individual objects: IRAS 16293-2224 – ISM: molecules – infrared: ISM: lines and bands

1. Introduction

Since the discovery of the first molecules in space in the 1940's (e.g. Adams 1941), the number of molecules detected and identified has increased to more than one hundred. With the increase in detections came an increase in the complexity of the detected molecules (e.g. Guelin et al. 1998). It is now clear that molecular clouds, and in particular clouds harboring newly formed stars, are extremely efficient factories of rather complex molecules.

The identification of more complex molecules fueled the search for amino acids - the pre-biotic molecules - in space. Glycine (NH_2CH_2COOH) is one of the simplest amino acids and therefore a privileged object of several detection attempts. The first attempts were carried out on high mass star forming regions like SgrB2, Orion and W3OH (Brown et al. 1979; Hollis et al. 1980; Snyder et al. 1983; Guelin & Cernicharo 1989) for the reason that they are the most luminous FIR sources in the sky. The searches were, however, unsuccessful: Combes et al. (1996) eventually argued that the upper limit which they obtained (N(Glycine) $\sim 5 \times 10^{13}$ cm^{-2}) cannot be further lowered, as in their search they had reached the line confusion limit.

Although high mass protostars were the first regions in the Galaxy in which complex molecules were detected, it is now clear that low mass protostars are also intense factories of complex molecules, and that their neighborhood may provide an even more favorable environment for the formation and survival of complex molecular species (van Dishoeck & Blake 1998). For example, the doubly deuterated formaldehyde D_2CO is about 20 times more abundant in the solar type protostar IRAS16293-2422 (hereinafter IRAS16293) than in Orion (Ceccarelli et al. 1998; Loinard et al. 2000). A search of two dozen protostars confirmed that low luminosity protostars have similar high abundances of D_2CO with respect to H_2CO (~ 0.1), whereas high luminosity protostars have much lower abundances (≤ 0.01) (Loinard et al. in preparation).

We have recently argued that solar type protostars, like their more massive counterparts, also possess *hot cores* where dust and gas temperatures exceed 100 K (Ceccarelli et al. 2000a,b). Our claim is based on the simultaneous modeling of H_2O, O, SiO and H_2CO line emissions from IRAS16293 by means of an accurate model of the structure of the protostellar envelopes (Ceccarelli et al. 1996). Additional evidence suggesting the presence of such hot cores inside low mass protostars is provided by NIR observations of the H_2O and CO absorption lines in El 29 (Boogert et al. 2000), a relatively evolved solar type protostar. In such hot cores the grain mantles evaporate, injecting plenty of complex molecules in the gas phase, as is the case for massive hot cores. In these cases, the so called "high temperature-driven chemistry" produces even more complex molecules (Charnley et al. 1997). A recent search suggests that formaldehyde has an abundance $\sim 10^{-9}$ in the hot cores of massive protostars (van der Tak, van Dishoeck & Caselli 2000). We have found 100 times more H_2CO in the hot core of the solar type protostar IRAS16293 (Ceccarelli et al. 2000b). Whether hot cores in low mass protostars are chemically richer than in massive protostars is not clear, but it is likely that they have different chemical compositions. In our opinion, solar-type protostars with signs of hot

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Send offprint requests to: Ceccarelli.Cecilia@obs.ujf-grenoble.fr cores may have a better chance of having detectable amounts of glycine than do massive protostars.

The conditions that may make low mass protostars more favorable for searching for glycine than massive protostars are:

a) their longer evolutionary timescale, which allow more time for the accretion and/or synthesis of molecules in the mantle
b) the less harsh environment to which molecules are exposed in the gas phase, which increases the probability of their survival.

Finally, the only place in the Universe where the presence of amino acids has definitively been shown is our planetary system, i.e. around a solar type star. Even though this does not imply at all that amino acids are formed in the protostellar phase it is a further reason to search for glycine around solar type protostars.

In this article we describe the first search for glycine carried out on a solar type protostar. After presenting the results of our observations (Sect. 2), we discuss in Sect. 3 the upper limit to the glycine column density and abundance that we derive from these observations and compare them with model predictions.

2. Observations and results

We searched for glycine line emission from IRAS16293, a well studied solar type protostar in the ρ Ophiuchus complex (distance 120 pc: Knude & Hog 1998). The observations were performed on Mar 18, 2000 with the IRAM 30m telescope near Pico Veleta (Spain).

The two conformations of glycine with the lowest energies are called conformer I and II respectively, where conformer II is $\sim 700\,\mathrm{cm}^{-1}$ higher in energy than conformer I (Lovas et al. 1995). Both conformers have numerous rotational transitions (~ 25000) in the radio to millimeter wavelength range (Pickett et al. 1998). Although higher in energy, conformer II has a dipole moment ~ 5 times larger than that of conformer I in a-type transitions (Brown et al. 1978 and Suenram & Lovas 1978). Finally, a-type transitions of conformer I have a slightly higher dipole moment than b-type transitions.

In our search for line emission from glycine we selected two observable frequency ranges: 216.305–216.815 GHz at 1.3 mm and 101.150–101.665 GHz at 3 mm. These bands include glycine lines expected to be among the strongest and whose upper level energies are relatively low ($\leq 200\,\mathrm{cm}^{-1}$), i.e. a-type transitions of conformer I. Besides, lines in the same band have similar level energies and line strengths, which makes it possible to lower the upper limit of the line intensity, averaging them together (see Discussion). Finally, in the selected bands, a few conformer II a-type lines are also present. The list of the glycine a-type transitions in the observed frequency ranges are reported in Table 1. In total, we have 9 a-type transitions from conformer I and 5 transitions from conformer II.

Two dual 1.3mm/3mm receivers were used simultaneously to observe the two frequency ranges. Each receiver was connected to a filterbank of 256 channels, each 1 MHz wide. The receivers were tuned in single side band and the image side band rejection was always higher than 10 dB. The system temperature throughout the observations was 120 K at 3 mm and 240 K at 1.3 mm.

Table 1. List of glycine a-type transitions in the two observed frequency ranges. The last two columns report the frequencies and low level energy of each transition.

Conformer	Transition	ν (GHz)	E_l (cm^{-1})
I	$16_{2,15}$-$15_{2,14}$	101.2214	27.1
I	$14_{3,11}$-$13_{3,10}$	101.2437	23.6
I	$16_{1,15}$-$15_{1,14}$	101.3390	27.1
II	$14_{6,8}$-$13_{6,7}$	101.1927	29.6
II	$14_{5,10}$-$13_{5,9}$	101.4249	27.3
I	$32_{6,27}$-$31_{6,26}$	216.3297	122.4
I	$31_{10,21}$-$30_{10,20}$	216.3614	129.9
I	$33_{5,29}$-$32_{5,28}$	216.5415	125.5
I	$33_{4,29}$-$32_{4,28}$	216.5880	125.5
I	$34_{4,31}$-$33_{4,30}$	216.8046	128.0
I	$34_{3,31}$-$33_{3,30}$	216.8063	128.0
II	$30_{7,24}$-$29_{7,23}$	216.4200	115.8
II	$30_{13,18}$-$29_{13,17}$	216.4270	140.9
II	$30_{13,17}$-$29_{13,16}$	216.4270	140.9

We searched for glycine line emission from two positions: the center of IRAS16293, at α(1950) = $16^{\rm h}29^{\rm m}20\overset{\rm s}{.}9$ and δ(1950) = $-24^{\circ}22'13''$, and a position 20″ south, where there is a peak in the deuteration of formaldehyde (see below). The observations were performed in position switching mode with the OFF position located at δ = -180″ and α = 0 from the center of IRAS16293. The total usable ON+OFF integration times at each position were 50 minutes at 1.3 mm and 115 minutes at 3 mm, yielding rms's of about 10 mK per MHz channel at 1.3 mm and 4 mK at 3 mm. The beam sizes are 21″ and 11″ at 3 mm and 1.3 mm respectively.

Fig. 1 shows the observed spectra towards the center and 20″ south of IRAS16293 at 1.3 mm and 3 mm respectively. No lines are seen where glycine transitions are expected, implying a 1σ upper limit to their signal of $T_{mb}\Delta v \leq 0.014$ K km s^{-1} in the 1.3 mm band and ≤ 0.012 K km s^{-1} in the 3 mm band respectively, assuming that the line is unresolved down to the resolution of the background spectrometer (1.4 km s^{-1} and 3.0 km s^{-1} at 1.3 mm and 3 mm respectively)[1].

It is worth noting the richness of the spectra in the central position (Fig. 1), which disappears in the 20″ position. In the figure, we report tentative identifications of the detected lines, based on the coincidence of a transition with the line frequency. Obviously, mere coincidence does not constitute a definitive identification for the large molecules in the figure, as these molecules have multiple transitions in the millimeter range: more lines in other frequency bands are necessary to definitively identify them. Nevertheless, the many lines detected from the central position almost certainly reflect the presence of large molecules. Those molecules are not seen 20″ south, in the cold and dense envelope surrounding IRAS16293 (Ceccarelli et al. 2000a,b). The 20″ south position in particular was chosen because the doubly deuterated formaldehyde, shown to be $\sim$ 10% of the

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[1] Several previous observations show that the linewidths of low energy transitions are ~ 2 km s^{-1} (e.g. van Dishoeck et al. 1995).

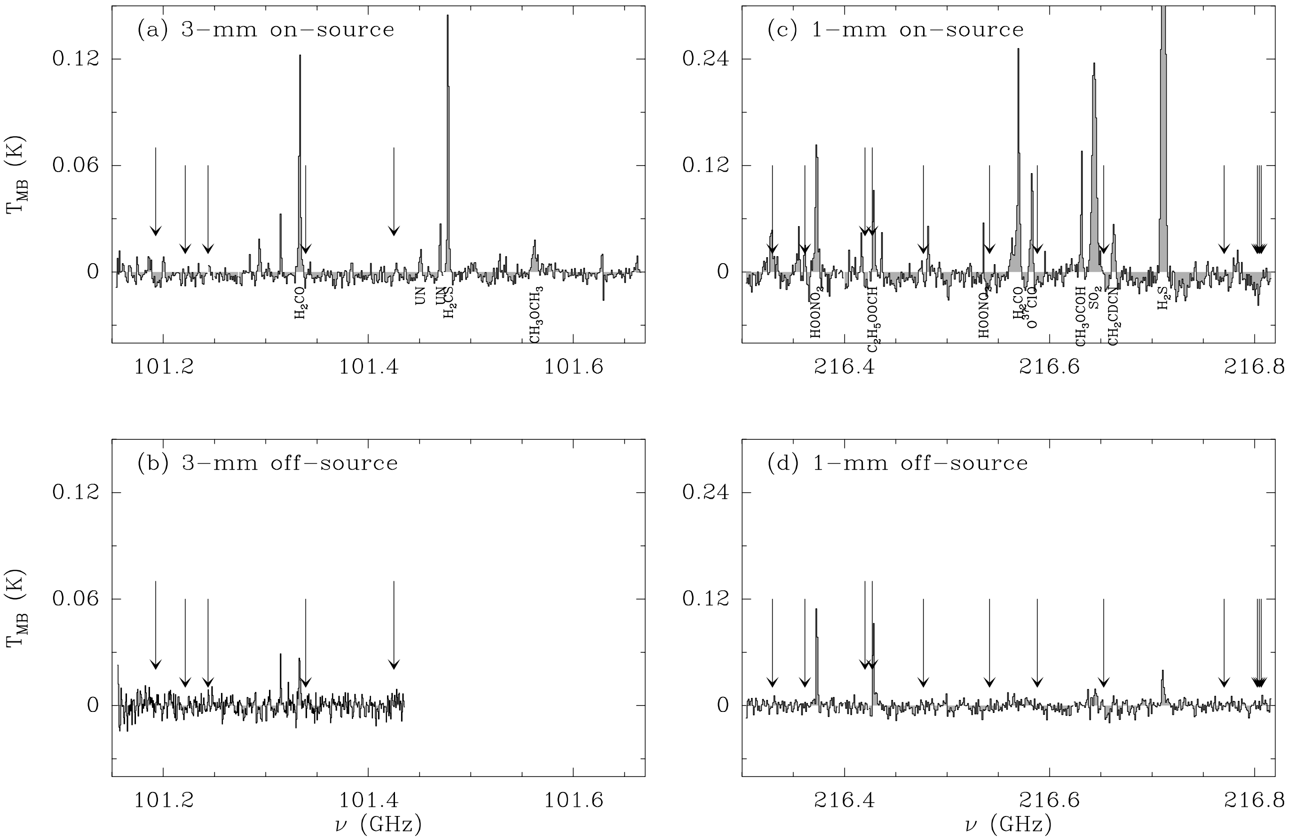

Fig. 1a–d. The spectra of the glycine line emission from IRAS16293 in the 3 mm (left panels) and 1.3 mm (right panels) bands. Upper panels refer to the central position while lower panels to the 20″ south position (see text). Line frequencies of the glycine are marked by arrows. The identification of the other lines is based only on the line coincidence with a transition of the marked species, not necessarily implying a real detection of the species (see text).

formaldehyde of this source (Ceccarelli et al. 1998; Loinard et al. 2000), has a peak emission in this position (Ceccarelli et al. in preparation). The absence of line emission from large molecules in the envelope may suggest that the large molecules are indeed formed in the interior of the envelope, probably in the ∼2″ hot core probed by the H_2O, SiO and H_2CO line emission (Ceccarelli et al. 2000a,b). In principle, it may be due to different excitation conditions rather than to a different chemical composition: however, in LTE conditions, a change of temperature from 20 K to 100 K would imply a gain of a factor 3 only in the population of levels at $\sim 30\,\mathrm{cm}^{-1}$, a factor smaller than the dilution factor given by the ∼2″ hot core size (the dilution factor is ~ 30 in the 1.3 mm band and higher in the 3 mm band).

3. Discussion

Assuming that the glycine lines are optically thin and LTE populated, the T_{mb} upper limit is directly proportional to the column density of glycine through the relation (Combes et al. 1996):

$$\mathrm{N(glycine)} \;=\; \frac{3Z}{8\pi^3}\,\frac{\mathrm{T}_{mb}\Delta\mathrm{v}}{\mu^2\mathrm{S}_{ul}}\,\frac{k}{\nu}\,\exp[E_u/k\mathrm{T}]\,\times \left[1-\frac{\exp[h\nu/k\mathrm{T}]-1}{\exp[h\nu/k\mathrm{T}_{bg}]-1}\right]^{-1} \qquad (1)$$

where Z is the partition function, S_{ul} is the line strength, μ is the dipole moment, E_u is the upper level energy, T is the gas temperature and T_{bg} is the background temperature.

The three lines of conformer I in the 3 mm band all have similar upper level energies ($\sim 27\,\mathrm{cm}^{-1}$) and line strengths ($\sim 15$). We therefore averaged the three lines together to increase the detection sensitivity. No line appears at a level of $7\,\mathrm{mK\,km\,s}^{-1}$. We performed the same analysis for the six lines in the 1.3 mm band (level energies $\sim\,125\,\mathrm{cm}^{-1}$, line strengths $\sim\,30$) and derived an upper limit of $6\,\mathrm{mK\,km\,s}^{-1}$. Using the molecule parameter values quoted by Combes et al. (1996), we obtained the curve of the upper limit of the glycine column density as a function of the gas temperature, shown in Fig. 2. Depending on the gas temperature, or in other words on where the glycine is supposed to originate, the upper limit of the glycine column density (averaged on the beam) varies from 0.7 to $1.5\times10^{13}\,\mathrm{cm}^{-2}$ for temperature varying from 20 K to 100 K. Using the density and temperature structure of the envelope surrounding IRAS16293 (Ceccarelli et al. 2000a), we can convert the upper limit of the glycine column density into an upper limit of the glycine abundance. In the cold envelope, the glycine abundance is therefore $\leq 1\times10^{-10}$. The limit of the abundance in the hot core is much higher, because of the dilution factor (~ 30 using the 216 GHz lines): $\leq 7\times10^{-9}$.

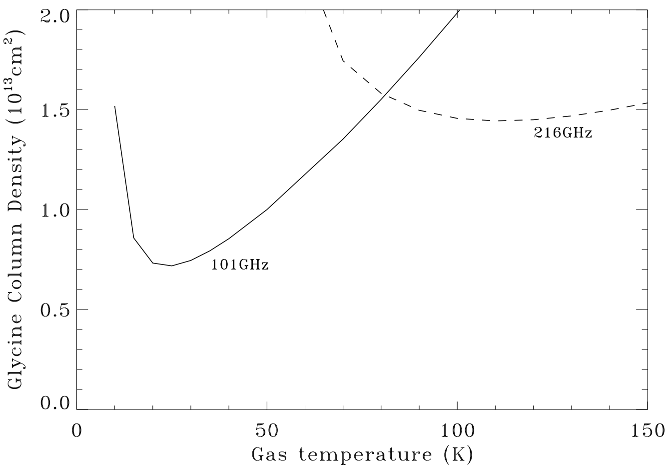

Fig. 2. The upper limit of the glycine column density as function of the gas temperature. The solid line refers to the conformer I a-type lines in the 101 GHz band; the dashed line refers to the 216 GHz band lines.

As already mentioned, glycine is among the simplest amino acids. A few theoretical studies have recently been performed to assess the possibility of glycine formation in space. There are two classes of such models for large molecule formation: the first describes the formation of large molecules via reactions occurring in the gas phase (e.g. Millar et al.1997), while a second class considers molecule formation on the grain surfaces (e.g. Tielens 1983). Glycine formation in the gas phase was recently studied by Chakrabarti & Chakrabarti (2000). In this model, the authors computed the glycine abundance in the envelopes surrounding low mass protostars and found that an abundance of a few 10^{-10} can be reached in the envelope at about 2000 AU ($\sim$ 13" in our source). The upper limit of the glycine abundance which we derive from our observations rules out such high values of glycine abundance in the cold region of the envelope. Indeed this is not surprising: in their chemical model, Chakrabarti & Chakrabarti (2000) used the UMIST database (Millar et al. 1997) where they have added several new species and reactions. In particular, the have assumed that glycine is formed from successive neutral-neutral reactions with rate constants taken to be 10^{-10} cm^3 s^{-1} (temperature independent). Such rapid reactions are unusual for neutral species and always involve radicals (open-shell species). In the case of glycine, since only stable (closed-shell) species are involved in its formation, the rate constants used by Chakrabarti & Chakrabarti (2000) are probably largely overestimated.

As previously stated, it is possible that glycine (as well as other large molecules) forms on grain surfaces due to multiple reactions on the grains which act as catalysts. Recently Bakes et al. (1999) reported a study of glycine formation on grain surfaces although exact estimates of abundances are not yet available. Charnley (1999) and Ehrenfreund & Charnley (2000) suggested that amino acids can form by combination of gas-grain chemistry involving evaporation of alcohols, amino alcohols and formic acid and exothermic reactions which lead to the synthesis of glycine and other amino acids in hot cores. Another possibility is the synthesis of glycine as a result of UV or X-ray irradiation of the grain dirty mantles. An experiment where ice composed of water with small amounts of formaldehyde and methanol (similar to that found around protostars) was illuminated by UV radiation resulted in the synthesis of quinones (Bernstein et al. 1999). Whatever the actual route of formation, if formed on grain mantles glycine would be released into the gas phase near the center, when the dust temperature exceeds 100 K (the ice sublimation temperature) in the hot core region. Of course, the survival of glycine in the harsh environment around protostars, where X-rays and UV photons are copiously emitted, may be difficult (Ehrenfreund, Bernstein, Dworkin, Sandford, Allamandola, in preparation). Our observations show that glycine is 7×10^{-9} less abundant than molecular hydrogen in the hot core region. Further searches at higher spatial resolutions could help to set a lower limit on the glycine abundance.

4. Conclusions

We have reported the first search for glycine in a solar type protostar. Our search was unsuccessful and provides an upper limit for the glycine column density of $\leq\ 5 \times 10^{12}$ cm^{-2} in the cold envelope and consequently to the glycine abundance of $\leq 1 \times 10^{-10}$. In the hot core, our upper limit on the glycine abundance is worse because of the beam dilution: $\leq 7 \times 10^{-9}$. We discussed briefly that these observations already challenge a recently published model of glycine formation in the gas phase (Chakrabarti & Chakrabarti 2000). Deeper searches directed towards solar type-protostars may, however, still detect traces of glycine, as we have not yet reached the confusion limit, like in the case of massive protostars (Combes et al. 1996).

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