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SO survey of massive cores

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Abstract. We present the results of a survey of several tens of dense high mass star forming (HMSF) cores in three transitions of the SO molecule at 30 and 100 GHz with the 100-m Effelsberg and 20-m Onsala radio telescopes. The physical parameters of the cores are estimated from the line ratios and column densities. Relative abundances are derived as well.

Keywords. ISM: clouds, ISM: molecules, ISM: abundances

1. Introduction

The chemistry of sulfur-bearing molecules is still poorly explored, especially in high mass star forming regions. These molecules can be important tracers of various phenomena in star forming regions, including outflows. Relative abundances of sulfur-bearing molecules can serve as chemical clocks (e.g. Viti *et al.* 2004) and as an indicator of the initial C/O ratio (e.g. Bergin *et al.* 1997). However, there are some discrepancies between models and observations (e.g. Herpin *et al.* 2009)

2. Observations and data analysis

We have observed 3 transitions of the SO molecule: $J_N = 1_0 - 0_1$ at 30.0016 GHz (with the 100-m Effelsberg telescope), $J_N = 3_2 - 2_1$ at 99.2999 GHz and simultaneously $J_N = 4_5 - 4_4$ at 100.0296 GHz (with the 20-m Onsala telescope). The beam widths of the Effelsberg and Onsala antennas at these wavelengths are similar ($\sim 30''$ and $\sim 40''$, respectively).

We analyze the line ratios with RADEX (Van der Tak *et al.* 2007). The line ratios were modeled in wide ranges of density and temperature. Estimates of the density and temperature from the line ratios are used for estimates of the SO column densities. SO abundances are derived by comparison with the $C^{18}O$ column densities, found from our Onsala observations (Zinchenko *et al.* 2000). The relative $C^{18}O$ abundance is assumed to be $X(C^{18}O) = 1.7 \times 10^{-7}$ (Frerking *et al.* 1982).

3. Results

At Onsala we have observed 35 sources. The $J_N = 3_2 - 2_1$ transition has been detected in all of them. The $J_N = 4_5 - 4_4$ transition has been detected in 3 objects: W3 (OH), W51 M and ON2 N. In Effelsberg we have observed 22 sources from the same sample. The SO line has also been detected in all of them. The $J_N = 3_2 - 2_1$ and $J_N = 1_0 - 0_1$ spectra for these sources are presented in Fig. 1.

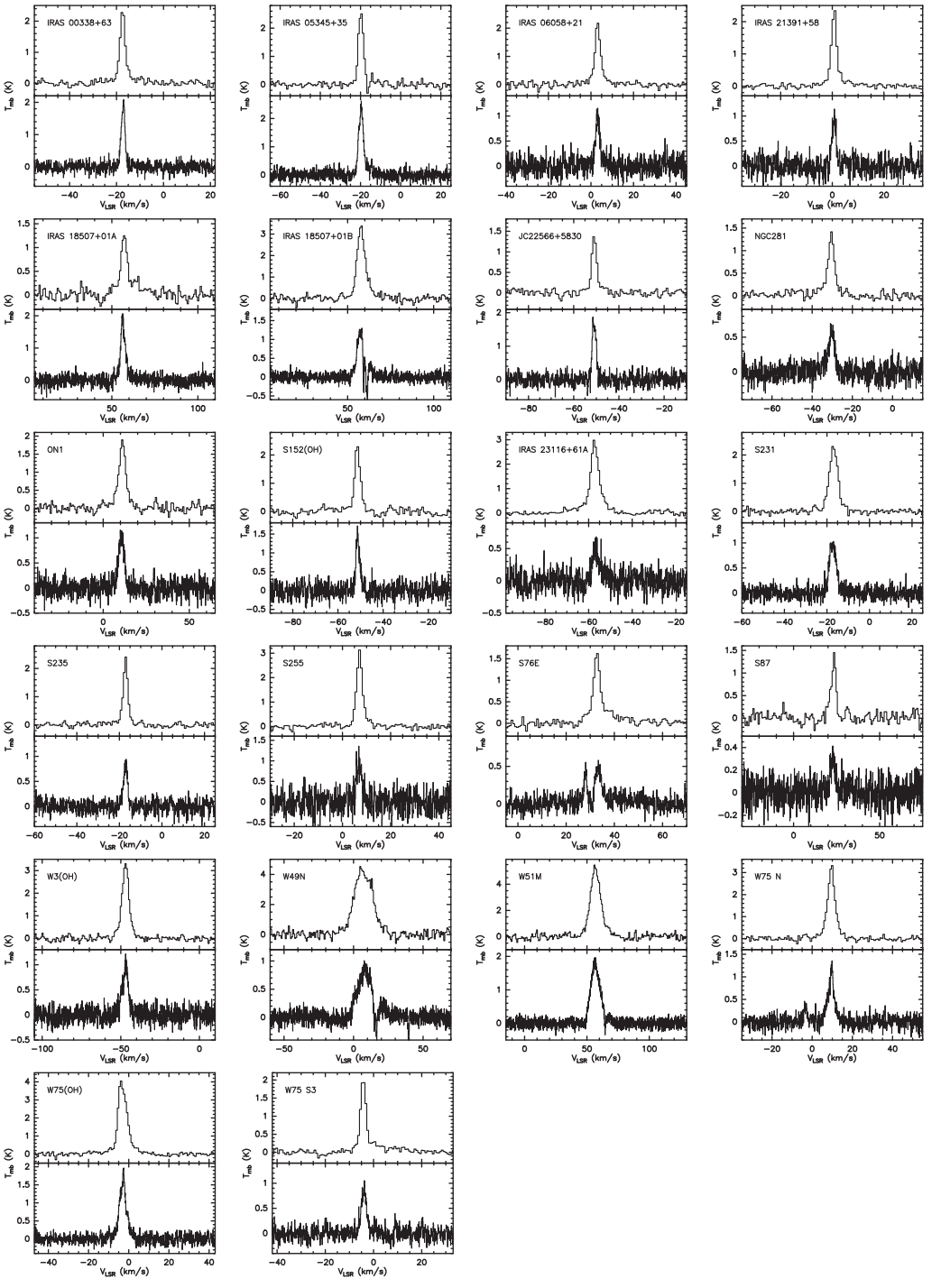

Figure 1. The $J_N = 3_2 - 2_1$ (upper panels) and $J_N = 1_0 - 0_1$ (lower panels) spectra for the 22 sources observed both in Effelsberg and in Onsala.

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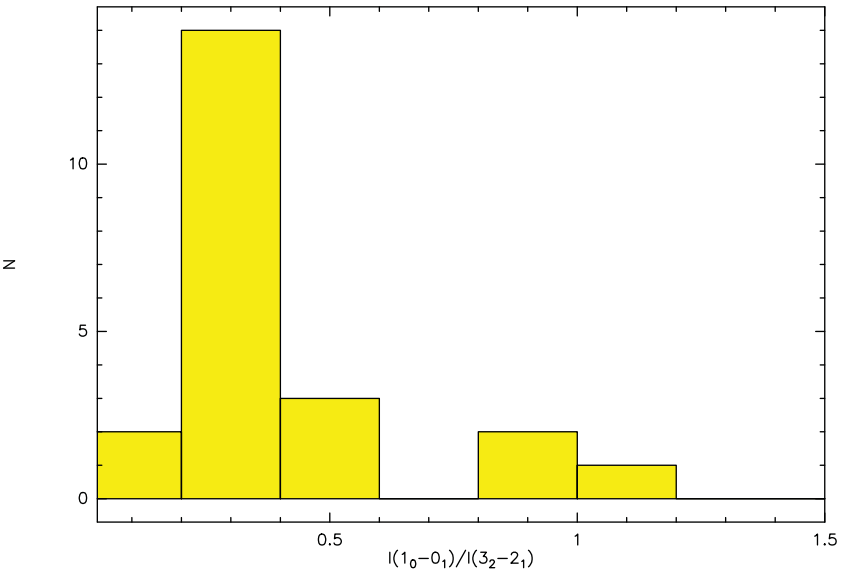

Figure 2. The histogram of the $(1_0 - 0_1)/(3_2 - 2_1)$ line intensity ratio.

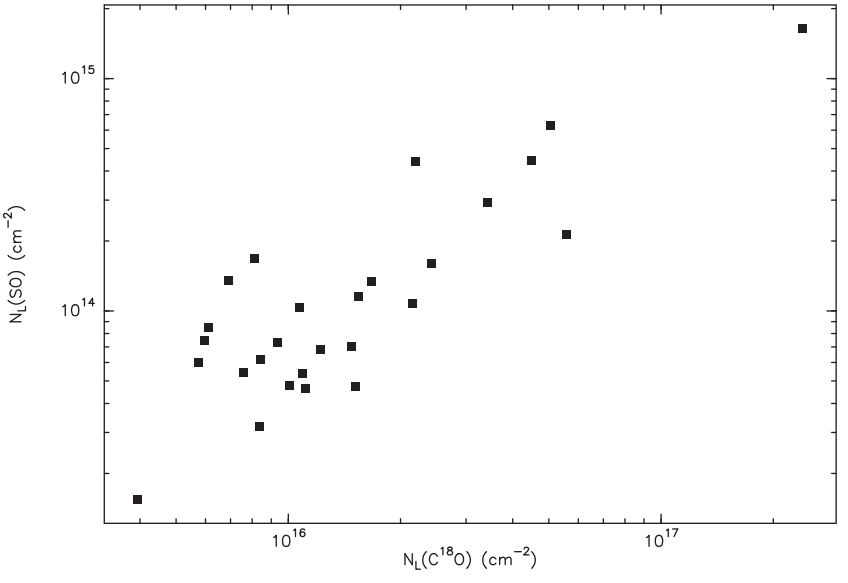

Figure 3. The SO column density in dependence on the $C^{18}O$ column density.

The $(1_0 - 0_1)/(3_2 - 2_1)$ intensity ratio lies in the range from ~ 0.15 to ~ 2 (Fig. 2). This corresponds to densities from $\sim 10^6$ cm^{-3} to $\sim 5 \times 10^3$ cm^{-3}. Most of the sources have a ratio of ~ 0.3, which corresponds to a density of $\sim 10^5$ cm^{-3}. The $(3_2 - 2_1)/(4_5 - 4_4)$ intensity ratio is ~ 20 for the detected sources. This detection indicates high temperature (> 50 K) and density ($> 10^6$ cm^{-3}).

There is a good correlation between the SO and $C^{18}O$ column densities (Fig. 3).

The SO relative abundance varies in the range $X(\mathrm{SO}) \sim (0.5-4) \times 10^{-9}$ with a median value of $\sim 1.3 \times 10^{-9}$. These values are rather close to the results of other recent studies

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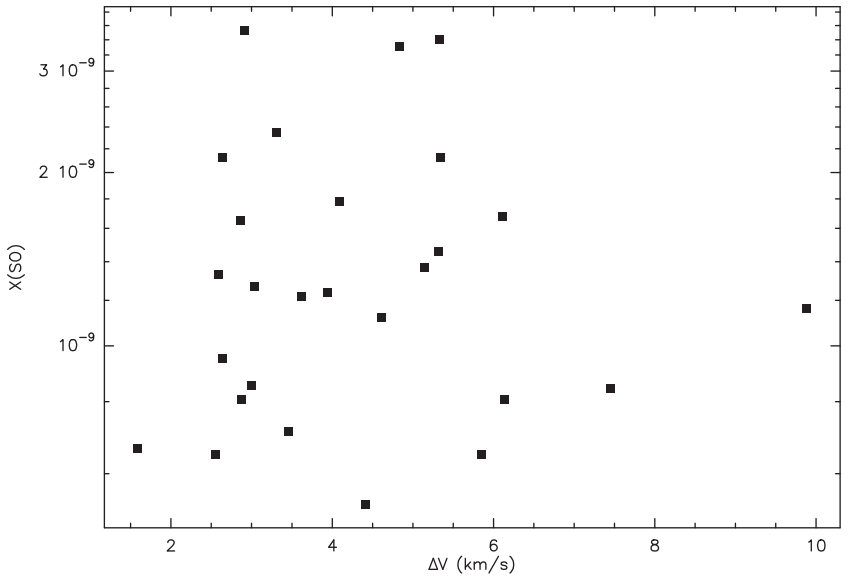

Figure 4. The SO relative abundance in dependence on the SO line width.

of similar objects (e.g. Li *et al.* 2015). We see no correlation between the SO abundance and the line width (Fig. 4).

4. Conclusions

We have surveyed 35 HMSF cores in the SO lines at 3 mm and 1 cm wavelengths. 22 objects have been observed (and detected) at both wavelengths. The line intensity ratios indicate a typical density of $\sim 10^5$ cm^{-3}. For several objects detected in the $J_N = 4_5 - 4_4$ line the density should be $> 10^6$ cm^{-3} and temperature > 50 K. There is a good correlation between the SO and C^{18}O column densities. The SO relative abundance varies in the range $X(\mathrm{SO}) \sim (0.5 - 4) \times 10^{-9}$ with a median value of $\sim 1.3 \times 10^{-9}$. There is no correlation between the $X(\mathrm{SO})$ and line width.

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