# ANOMALOUS ABSORPTION IN COSMIC $H_2CS$ MOLECULE

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## Abstract

Absorption against the Cosmic Microwave Background (CMB), called the anomalous absorption, is an unusual phenomenon. The transition $1_{11} - 1_{10}$ at 4.829 GHz of formaldehyde ($H_2CO$) was the first one showing the anomalous absorption. The $c$-$C_3H_2$ is the second molecule showing anomalous absorption through its transition $2_{20} - 2_{11}$ at 21.590 GHz. Structure of thioformaldehyde ($H_2CS$) is very similar to that of the $H_2CO$. Therefore, we have investigated about the physical conditions under which the transition $1_{11} - 1_{10}$ at 1.0465 GHz of $H_2CS$ would be found in anomalous absorption in cool cosmic objects. As in case of $H_2CO$, the anomalous absorption of $1_{11} - 1_{10}$ of $H_2CS$ is found sensitive to the relative collisional rates and it requires that the collisional rate for the transition $1_{11} - 2_{11}$ must be smaller than that for the transition $1_{10} - 2_{12}$.

## 1 Introduction

Structure of thioformaldehyde ($H_2CS$) is very similar to that of the $H_2CO$ (Figure 1). Keeping in view the similarity of $H_2CO$ and $H_2CS$, in the present investigation, we attempted to look into the physical conditions under which the transition $1_{11} - 1_{10}$ at 1.0465 GHz of $H_2CS$ may be found in anomalous absorption.

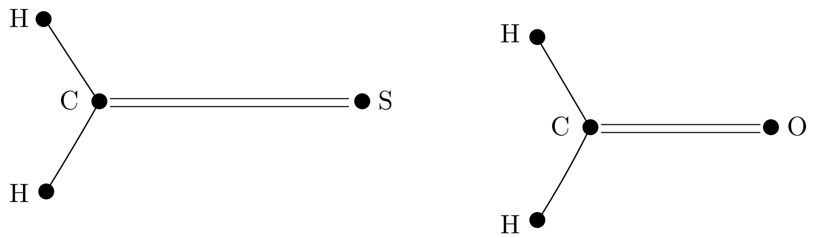


Figure 1: Structures of $H_2CS$ and $H_2CO$ molecules are very similar to each other.

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## 2 Thioformaldehyde

Thioformaldehyde is an $a$-type asymmetric top molecule having electric dipole moment 1.6491(4) Debye (Fabricant, 1977).

Recently Maeda et al. (2008) studied pure rotational spectrum of $H_2CS$ and derived very accurate molecular and distortional constants given in Table 1 where the observed frequencies were fitted to Watson's $S$-reduction Hamiltonian using $I^r$ representation (Gordy & Cook, 1984).

## 3 Anomalous absorption

Let us try to find out the requirement for the anomalous absorption for the transition $1_{11} - 1_{10}$. For this transition, the levels of the doublet $J = 1$ are radiatively connected to the levels of $J = 2$ doublet only, as

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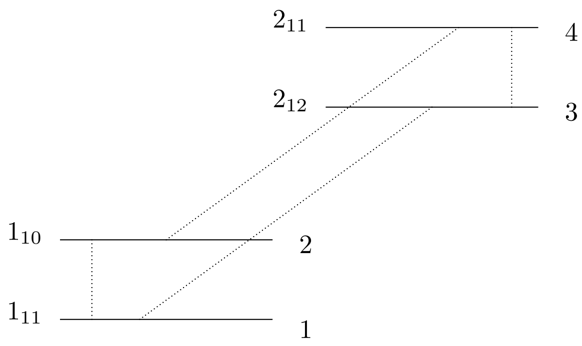
shown in the following figure. For convenience, the levels are labeled as 1, 2, 3, 4. The radiatively allowed transitions between the levels are shown by the dotted lines.




In the optically thin limit ($n_{H_2} C_{ul} << A_{ul}$, *i.e.*, the collisional rates are negligible in comparison to the radiative ones), for these four energy levels, the statistical equilibrium equations may be expressed as the following (Chandra et al., 2006a):

$$
\begin{aligned}
n_1(C_{13} + C_{14}) &= n_3 A_{31} \\
n_2(C_{23} + C_{24}) &= n_4 A_{42} \\
n_3 A_{31} &= n_1 C_{13} + n_2 C_{23} \\
n_4 A_{42} &= n_1 C_{14} + n_2 C_{24}
\end{aligned}
$$

These equations can be rearranged as

$$\frac{n_2}{n_1} = \frac{C_{14}}{C_{23}}$$

For anomalous absorption, we require $n_2 < n_1$, showing that $C_{14} < C_{23}$. This shows that the transition between the levels $1_{11}$ and $1_{10}$ would show absorption against the CMB provided $C_{14} < C_{23}$. Since equation (**??**) gives $C_{14} = C_{23}$, we have to modify either $C_{14}$, $C_{23}$ or both of them in order to get anomalous absorption.

## 4 Results and discussion

In our investigation, NLTE occupation numbers of levels are calculated in an on-the-spot approximation by using the method discussed in section 4, where the external radiation field, impinging on a volume element generating the lines, is the CMB only. In the present investigation, a set of 25 linear equations coupled with 36 equations of radiative transfer is solved through the iterative procedure for the given values of $n_{H_2}$ and $\gamma$. In order to include a large number of cosmic objects where $H_2$CS may be found, numerical calculations are carried out for the wide ranges of physical parameters. In the present investigation, we have taken $\gamma = 10^{-6}$ cm$^{-3}$ (km/s)$^{-1}$ pc and $10^{-5}$ cm$^{-3}$ (km/s)$^{-1}$ pc. For lower value of the column density, the intensity of the line may not be observable. The molecular hydrogen density $n_{H_2}$ is varied over the range from $10^3$ to $10^7$ cm$^{-3}$, and calculations are made for the kinetic temperatures 10 K, 20 K, 30 K and 40 K, as the temperature in a cool cosmic object would be around that.

The collisional rates obtained from equation (**??**) give $C_{14} = C_{23}$. Hence, the required condition $C_{14} < C_{23}$ is not produced. This condition can be produced either by increasing the collision rates between the levels $1_{10}$ and $2_{12}$ by some positive factor greater than 1 or by reducing the collision rates between the levels $1_{11}$ and $2_{11}$ by a positive factor greater than 1 or by doing both.

(i) We increased the collisional rates for the transitions between the levels $1_{10}$ and $2_{12}$ by a factor of 2 and the result given in Figure **??** show the brightness temperature $T_B$ (K) (column 1), excitation temperature $T_{ex}$ (K) (column 2) and the optical depth $\tau_\nu$ (column 3) as a function of hydrogen density $n_{H_2}$ for kinetic temperatures of 10 K, 20 K, 30 K and 40 K for transition $1_{10} - 1_{11}$ of $H_2CS$. Solid line is for $\gamma = 10^{-5}$ cm$^{-3}$ (km/s)$^{-1}$ pc and the dotted line for $\gamma = 10^{-6}$ cm$^{-3}$ (km/s)$^{-1}$ pc. Keeping in view the accuracy of collisional rates available for some molecules, the factor of 2 is not very large. The collisional rate coefficients $C_{14}$ and $C_{23}$ used here are given in Table 4, as a function of temperature. In order to investigate sensitivity of our results to the collisional rates, we enhanced the collisional rates for the transitions with $\Delta k_a = 0$ by a factor of 10 which may be taken as an extreme case (Chandra & Shinde, 2004). The absorption feature of the line is found to remain unaffected. However, the position of the minimum value of $T_B$ is found to shift towards the low density region. With enhanced collisional rates the results for the brightness temperature $T_B$ (K) are shown in column 4 of Figure **??**.

(ii) When, we reduced the collisional rates for the transitions between the levels $1_{11}$ and $2_{11}$ by a factor of 2, the results given in Figure **??** show the brightness temperature $T_B$ (K) (column 1), excitation temperature $T_{ex}$ (K) (column 2) and the optical depth $\tau_\nu$ (column 3) as a function of hydrogen density $n_{H_2}$ for kinetic temperatures of 10 K, 20 K, 30 K and 40 K for transition $1_{10} - 1_{11}$ of $H_2CS$. Solid line is for $\gamma = 10^{-5}$ cm$^{-3}$ (km/s)$^{-1}$ pc and the dotted line for $\gamma = 10^{-6}$ cm$^{-3}$ (km/s)$^{-1}$ pc. The collisional rate coefficients $C_{14}$ and $C_{23}$ used here are given in Table 5, as a function of temperature. In order to investigate sensitivity of our results to the collisional rates, here also we enhanced the collisional rates for the transitions with $\Delta k_a = 0$ by a factor of 10. The absorption feature of the line is found to remain unaffected. However, the position of the minimum value of $T_B$ is found to shift towards the low density region. The results for the brightness temperature $T_B$ (K) are shown in column 4 of Figure **??**.

Variation of brightness temperature $T_B$ (K) with the molecular hydrogen density $n_{H_2}$ shows that the maximum anomalous absorption occurs around a density of $10^4$ cm$^{-3}$. For the higher densities, the brightness temperature $T_B$ (K) increases and goes to a value higher than the background temperature (2.73 K) and then saturates to the value of the background temperature. In the low density region also the brightness temperature $T_B$ (K) tends to the background temperature.

Figures 1 and 2 show that the maximum anomalous absorption is at the kinetic temperature of 10 K. The anomalous absorption decreases as the kinetic temperature in the cosmic object increases.

In order to confirm our investigation, we did the calculations for $H_2CO$ molecule where the molecular and distortional constants are taken from Bünken et al. (2003), given in column 3 of Table 1. Though the collisional rates for $H_2CO$ are given by Green et al. (1978), but for $H_2CO$ also we used the scaled values given by equation (**??**) and considered the similar variation for collisional rates. The collisional rate coefficients used in case of $H_2CO$ are the same as given in Tables 4 and 5. The behaviour for the transition $1_{11} - 1_{10}$ for $H_2CO$ was found similar to that of $H_2CS$. The anomalous absorption in $H_2CO$, by using the collisional rates of Green et al. (1978) has been investigated by Chandra et al. (2006b) and there also we found the similar behaviour.

## 5 Conclusions

Here, we have used scaled values of collisional rates for $H_2CS$, and therefore, our results are qualitative in nature. We found that the $1_{11} - 1_{10}$ may show anomalous absorption around the density of $10^4$ cm$^{-3}$. This transition may help in identification of the molecule in cool cosmic objects, because the kinetic temperature may not be sufficient for generating the emission spectrum. But the anomalous absorption may be observed as the ground state is always populated. Since the value of $\mu^2 S(2I+1)$ for the transition $1_{10} - 1_{11}$ is quite large, the transition $1_{10} - 1_{11}$ has large probability for its detection. Our future plan is to calculate collisional rates. Though the job is quite cumbersome and lengthy. Once the collisional rates are available, we can go for the quantitative results.

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