The $C^{18}O/C^{17}O$-ratio in the ρ Oph cloud and across the Galaxy

J.G.A. Wouterloot[1], J. Brand[2], and C. Henkel[3]

[1] Joint Astronomy Centre, Hilo, HI (USA) j.wouterloot@jach.hawaii.edu
[2] Istituto di Radioastronomia, CNR, Bologna (I) brand@ira.cnr.it
[3] Max-Planck Institut für Radioastronomie, Bonn (D) p220hen@mpifr-bonn.mpg.de

1 Abstract

We report the results of an investigation to determine the $^{18}O/^{17}O$-ratio across the Galaxy and in a local cloud (ρ Oph). The *measured* J=1–0-ratio is 3.36 ± 0.10 and constant between the Galactic Center and $R_{\rm GC} \approx 17$ kpc, while the J=2–1-ratio increases from ~ 2 to ~ 5 in this range, which can be explained by excitation- and optical depth effects. The best value of the $^{18}O/^{17}O$-ratio in the local interstellar medium is 4.1 ± 0.2.

2 Introduction and Observations

Abundance ratios of interstellar isotopomers are a powerful tool to study the chemical evolution of the Galaxy. One such ratio is that of the rare species of oxygen, ^{18}O and ^{17}O, as measured from the isotopomers of CO. For the galactic disk and -center region, [1] reported average $^{18}O/^{17}O$ ratios of 3.65±0.15 and 3.5±0.2, respectively. He also found that the $^{18}O/^{17}O$ ratio, determined from the integrated line intensity ratios of $^{12}C^{18}O(1\text{–}0)$ and $^{12}C^{17}O(1\text{–}0)$, shows no significant gradient with galactocentric distance $R_{\rm GC}$ out to 10kpc. In fact, models by [2] suggest that after a few Gyr the ratios in the Galaxy should be independent of $R_{\rm GC}$. There is, however, a discrepancy between the interstellar medium values and the much higher (5.5) solar system one. A low value of 1.6 ± 0.3 was obtained in the LMC by [3]. These results suggest that the $^{18}O/^{17}O$ ratio depends on metallicity.
The sources observed by [1] are located in a limited range of $R_{\rm GC}$, and we have reobserved these sources with higher angular resolution and have extended our study to sources out to $R_{\rm GC} \approx 17$ kpc (solar circle: $R_\odot$=8.5 kpc). While [1] only observed the J=1–0 transition, our observations also include the J=2–1 rotational lines.
To study in detail excitation and opacity effects that could affect the measured $^{18}O/^{17}O$ ratios and radial gradients, we have also observed the ρ Oph cloud ($d \sim 140$ pc) because of the large range in column densities found therein, as shown by earlier observations, because of the high linear resolution that can be obtained towards this object, and because this provides an

opportunity to determine new accurate values of the ^{18}O/^{17}O ratio in the solar neighbourhood.

Using the IRAM 30-m telescope we observed 22 sources with $0< R < 17$ kpc, some of which at several offset positions, in ^{13}CO, C^{18}O, and C^{17}O J=1–0 and 2–1. In the ρ Oph cloud 21 positions were observed with the SEST in ^{12}CO, ^{13}CO, C^{18}O, and C^{17}O J=1–0 and 2–1, and the six strongest positions were observed with the JCMT in C^{18}O and C^{17}O J=3–2.

3 Analysis and Results

3.1 Galaxy-wide ratio

We obtained ^{18}O/^{17}O ratios from the integrated line intensities correcting for the difference in frequency, following [1]. The resulting ratios as a function of $R_{\rm GC}$ are shown in Fig. 1. With the exception of (at least one of) the two sources for which we have only upper limits for C^{17}O, the J=1–0-ratio is essentially constant accross the Galaxy at 3.56 ± 0.16 (unweighted) or 3.36 ± 0.10 (weighted with error of data points), consistent with the values of [1]. For J=2–1, the ratio is increasing with distance from the galactic centre. However, the ρ Oph data points (red in Figs. 1a, b) show that at each radius there can be a large spread in the observed ratios.
The question now is, whether the galactic gradient found in the 2–1 ratios is real, or a consequence of the small number of sources observed combined with the intrinsic spread in values, in combination with excitation and optical depth effects.

3.2 Local ratio

The ratios for ρ Oph were analysed in various ways, obtaining column density ratios with different assumptions for the excitation temperatures ($T_{\rm ex}$) of the molecules. In Fig. 1c and d the observed ratios are shown as a function of integrated C^{17}O(1–0) intensity, corrected only for the difference in frequency. Our values are compared with the value of [1] (dashed line) and that of [4] (dotted line); the latter authors observed one of our positions in ^{13}C^{18}O and ^{13}C^{17}O. In Fig. 1d are also the ratios for 6 of the present positions observed in J=3–2. The J=1–0-ratio is at a more or less constant value of about 3.8 throughout the cloud, with the exception of the cloud center (2.2), which indicates τ(C^{18}O)>1 for J=1–0 and $\tau \approx 2-3$ for higher transitions.
In Figs. 1e and f are shown the column density ratios. Average ratios derived from the J=1–0 transition (omitting the cloud centre) depend on the assumptions used to derive column densities, and the range is from 3.76 ± 0.12 (assuming C^{18}O and C^{17}O $T_{\rm ex}$ are equal to those of ^{12}CO) to 4.06 ± 0.24 (using $T_{\rm ex}$ derived from respective (2–1)/(1–0) ratios, assuming lines are optically thin). The latter value is close to the 4.15 ± 0.15 derived towards our

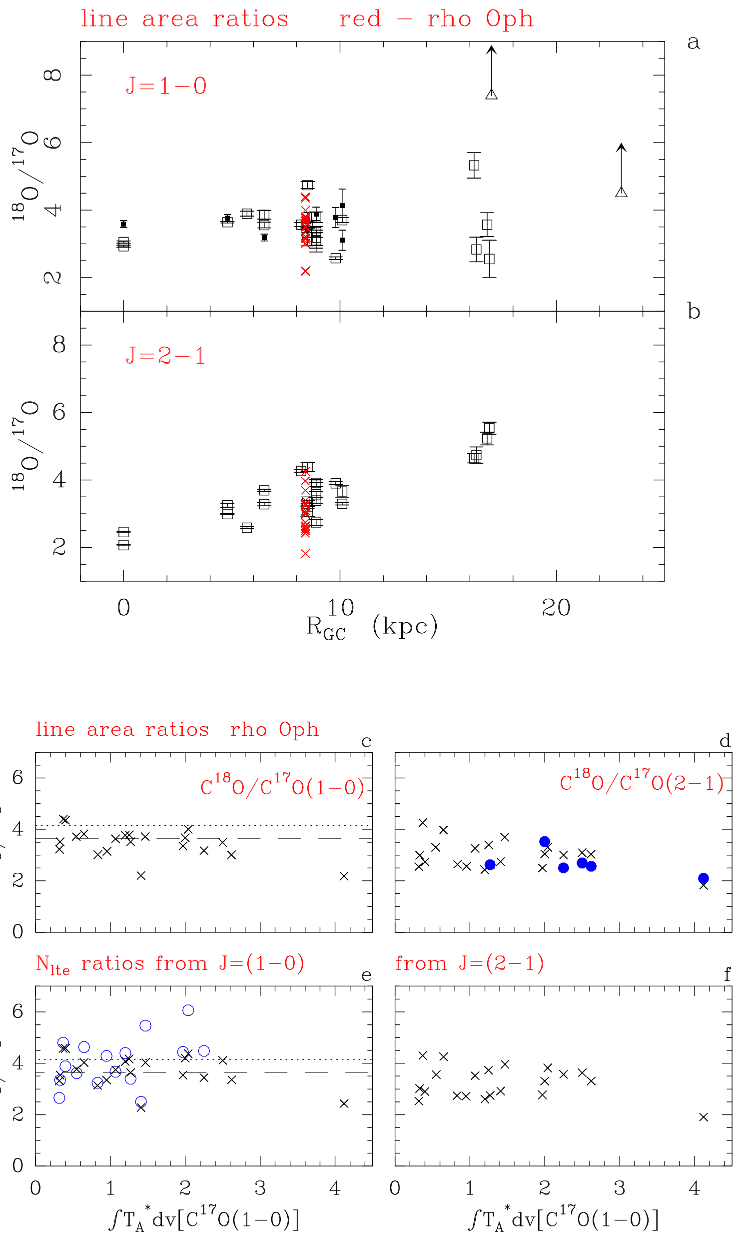

Fig. 1. a, b Ratio $C^{18}O/C^{17}O$(1–0) (a) and (2–1) (b) as a function of distance from the galactic centre R_{GC}. Open squares indicate our new results. The open triangles indicate lower limits for DDT94 Cloud 1 and 2 ([6]) from less sensitive data. Filled symbols: results from [1]; red crosses: our ρ Oph data. **c–f** $C^{18}O/C^{17}O$ isotopomeric ratios as a function of integrated $C^{17}O$(1–0) intensity for J=1–0 (c, e; crosses), J=2–1 (d, f; crosses) and J=3–2 (d; filled circles). In (c, d) the $C^{18}O/C^{17}O$ line area ratios have only been corrected for the frequency difference. The dashed line indicates the ratio found by Penzias for the galactic disk, and the dotted line the result from [4] from $^{13}C^{18}O$ and $^{13}C^{17}O$(1–0). In (e, f) we show the column density ratios derived from the J=1–0 (e) and J=2–1 (f) transitions, respectively, assuming T_{ex} for $C^{18}O$ and $C^{17}O$, derived from $T_A^*(^{12}CO)$ (crosses) or from the (2–1)/(1–0) T_A^* ratios (circles).

position with the highest column density from observations of the optically thin transitions $^{13}C^{18}O$ and $^{13}C^{17}O(1–0)$ by [4].

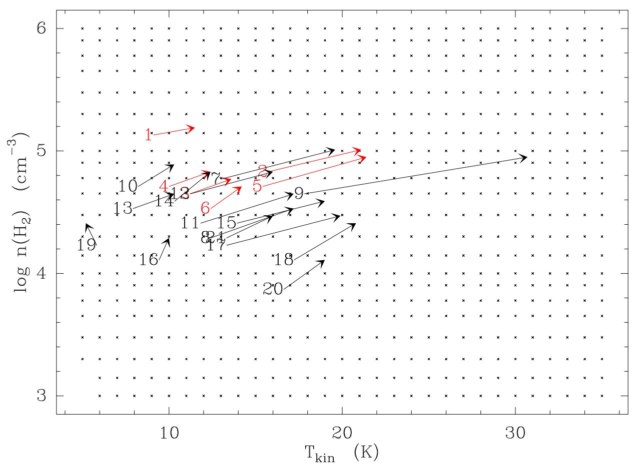

Fig. 2. Results of LVG-calculations towards ρ Oph for the 21 positions, assuming an intrinsic $C^{18}O/C^{17}O(1–0)$-ratio of 4.0 and a $C^{18}O$-abundance of 1.7×10^{-7} ([5]). The heads of the arrows are for $T_{\rm mb}$-ratios and the tails for $T_{\rm A}^*$-ratios.

We also analysed the $C^{17}O$ or $C^{18}O$ data with LVG-calculations; in these calculations we have to assume abundances for both molecules. With a $[C^{18}O]/[H_2] = 1.7 \times 10^{-7}$ ([5]) and $^{18}O/^{17}O$-ratios of 3.5 or 4.0, there are only small differences in χ^2 fits to the data. The resulting densities and kinetic temperatures are shown in Fig. 2 and depend on whether they are derived from $T_{\rm A}^*$ or $T_{\rm mb}$ (tail and head of arrows, respectively) temperatures. There is a slight decrease in kinetic temperature with decreasing $T_{\rm A}^*$, from about 10 K in the cloud center to 20 K in the outer parts. First runs of the LVG-model for clouds at large $R_{\rm GC}$ indicate relatively low densities (7000 cm^{-3}) compared with ρ Oph.

References

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