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THE BEHAVIOUR OF THE [O I] 63 \mu m and [O I] 145 \mu m LINES IN THE \rho OPHIUCHI CLOUD

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ABSTRACT

The dense cores B 1, B 2 and C North in the active star forming \rho Oph cloud have been observed with the ISO LWS (\lambda = 43–197 \mu m, R = 140 – 330). Detailed modelling of the FIR spectra shows that the emission originates in a PDR on the rear side of the cloud. However, the behaviour of the O I ground state lines ([O I] 63 \mu m, [O I] 145 \mu m) appears anomalous in the sense that observed flux ratios are too small compared to those predicted by theoretical models of O I excitation and line transfer. Based on the LWS data, we argue that self absorption in the [O I] 63 \mu m line by cool foreground material is not a viable explanation in the case of \rho Ophiuchi: the expected reduction in [O I] 63 \mu m flux towards the dense cores is not reflected by the data. In contrast, the [C II] 158 \mu m and [O I] 63 \mu m lines behave in accordance with model predictions. It seems likely, therefore, that it is not the [O I] 63 \mu m line being too weak, but that the [O I] 145 \mu m line is relatively too strong and we propose that slight masing in the [O I] 145 \mu m line is responsible for the observed line ratio anomaly.

Key words: ISM; Molecular Clouds; \rho Ophiuchi Cloud; PDRs; Star Formation.

1. INTRODUCTION

The relative strengths of the fine structure lines of atomic oxygen, viz. O^0 \rightarrow 3P_1 \rightarrow 3P_2 (63 \mu m) and O^0 \rightarrow 3P_1 (145 \mu m), are known to be difficult to predict theoretically for a number of astronomical sources (e.g., Tielens & Hollenbach 1985a & b; Saraceno et al. 1998). The ground state of O^0 is inverted, with the 145 \mu m line connecting the middle level with the upper level, more than 300 K above ground. The 63 \mu m transition, on the other hand, occurs between the middle level (\Delta E/k \gtrsim 200 K) and the lowest level at zero energy.

In several observed cases, 63 \mu m absorption (and/or scattering) by cool material along the line of sight towards the emitting source was directly suggested by the data (e.g., Baluteau et al. 1997). Such absorption could be expected to apply also to selected regions in the nearby (150 pc) \rho Oph cloud, harbouring a number of well studied dark and dense cores. In fact, the \rho Oph cloud could serve as a case study, since (1) the geometry of the emitting and of the putative absorbing regions is known, (2) the distribution of the volume and the column density is known, and (3) the spatial distribution and local strength of the UV-field (expressed in units of G_0, the integrated flux of the local interstellar field) is known from observation and theoretical modelling (Liseau et al. 1998, hereafter Paper I).

The regions \rho Oph B and \rho Oph C (Loren et al. 1990) appear as dark patches at wavelengths at least as long as 15 \mu m (see the ISOCAM image by Abergel et al. 1996). It is therefore most likely that the illuminating source (HD 147889, see: Paper I) is situated behind the bulk of the cloud and, consequently, that most of the PDR (Photon Dominated Region) emission originates at the rear side of the cloud. This scenario is in agreement with our detailed model presented in Paper I. In the present contribution, we examine the [O I] 63 \mu m and [O I] 145 \mu m observations with the LWS towards the dense cores \rho Oph B 1, B 2 and C 1 (C North).

2. OBSERVATIONS AND DATA QUALITY

In Fig. 1, the pointings of the ISO LWS (Kessler et al. 1996; Clegg et al. 1996) towards \rho Oph B are shown superposed onto a map in the emission of CS (J=5-4) (unpublished 15m SEST data of R. Liseau). The integrated CS line intensity traces the density distribution of the cloud. The high density clumps \rho Oph B 1 (south-west) and \rho Oph B 2 (north-east) are clearly revealed in this figure. The LWS data are spatially oversampled in the scan direction (\Delta \approx 40''/LWS-beam about 80'') and displayed in Fig. 2, where the positions of \rho Oph B 1 (b 4) and \rho Oph B 2 (b 11) are identified. The IRAS source IRS 37 (Wilking et al. 1989) is at b 6.

In Figs. 2 and 3, the positions of b 3 and c 6 are especially marked. The latter refers to a different scan (Paper I), which was obtained at a different date. The pointing towards c 6 was originally intended to coincide with b 3 for cross calibration checks. The actual angular distance between the two positions is only 25'', implying that these observations should


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3. DISCUSSION AND CONCLUSION

In a scenario, where a small [O\textsc{i} 63 \mu m]/[O\textsc{ii} 145 \mu m] line ratio (< 10) is caused by decreased 63 \mu m line flux due to self absorption in cool foreground material, one would expect the [O\textsc{i} 63 \mu m] flux to anticorrelate with the column density of the cold gas. Such behaviour is not observed anywhere in \rho Oph, however (see also Figs. 2 and 3). Surprisingly, rather the opposite seems to occur, viz. that the line strength appears to grow with the column density of cold gas (near their centers, the temperature of the cores is as low as 10 K). Since $G_3$ is approximately constant over the core regions and the [O\textsc{i} 63 \mu m] emission is not optically very thick ($\tau_0 \sim 1$ – a few, Paper I), the increase in line flux could reflect an increase in density in the emitting regions, i.e. in the PDR. Such increase could refer to either (1) an enhanced hydrogen density, for a constant (depleted) oxygen abundance or (2) an augmented abundance of atomic oxygen relative to hydrogen. The latter could be due to gas-grain chemical activity. However, on the basis of the available observational evidence we are not able to distinguish one possibility from the other. Alternatively, the IRAS source IRS37 could contribute significantly to the [O\textsc{i} 63 \mu m] flux.

We recall the fact that the [C\textsc{ii}] 158 \mu m and [O\textsc{i} 63 \mu m] lines behave in accordance with model predictions. It thus seems that the encountered difficulties are due to [O\textsc{i} 145 \mu m] alone and that the observed [O\textsc{i} 63 \mu m]/[O\textsc{i} 145 \mu m] line ratios in \rho Oph are not easily explained. In particular, self absorption of [O\textsc{i} 63 \mu m] seems to be ruled out. Should our comprehension of the source geometry be incorrect,
the self absorption picture would suffer even further, since the PDR would then be on the side of the cloud facing the Earth and little, if any, foreground material to absorb or scatter 63 μm photons would be available. It seems more likely, therefore, that the causes of small line ratios are not external, but internal to the physics of 63 excitation and/or line transfer. In Paper I, we have examined a large number of possible explanations and reached the conclusion that the hypothesis of slight missing in the [OⅠ] 145 line seems most promising. A physical mechanism, accomplishing the maser action, should be investigated in more detail.

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REFERENCES