Large column densities and $^{12}\text{CII}$ 158 μm self-absorption in Orion B

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Abstract. We present a preliminary analysis of the self-absorbed [CII]-spectra observed with SOFIA/GREAT towards NGC 2024. Together with the detected $^{13}\text{CII}$ hyperfine satellites, the observed spectra require surprisingly high column densities of $^1\text{C}^+$, both in the warm core and the foreground absorption component. Such high column densities are a challenge to explain with present state-of-the-art PDR models of the UV/molecular cloud interaction.

Keywords. ISM: molecules — ISM: clouds — ISM: individual (Orion B)

As part of the basic science program of SOFIA during 2011 we mapped a 192″ × 150″ area in total power on-the-fly mode in the Orion B region (Graf et al. 2012), where the first $^{12}\text{CII}$ line detection had been reported in 1980 (Russell et al. 1980), more than 30 years ago. The OFF position was confirmed both by former observations (Jaffe et al. 1994) and by a comparison measurement to a far-away off-position, to be free of [CII]-emission. For this poster contribution we concentrate on the interpretation of the $^{12}\text{CII}$ and $^{13}\text{CII}$ spectrum, obtained by averaging the map over a 60″ × 15″ box centered around the position of peak emission (Graf et al. 2012).

The fact that the $^{13}\text{CII}$ profile does not match the double peaked isotopic CO profiles (see Graf et al. 1993), but rather shows a single component at a velocity in between the two molecular emission components and a line width slightly larger than either of those, implies, that the double peaked $^{12}\text{CII}$ profile is self-absorbed. The $^{13}\text{CII}$ integrated line in the optically thin, high density and high temperature limit requires a total $^{12}\text{C}^+$-column density of about $1.3 \times 10^{19} \text{ cm}^{-2}$ (with $^{12}\text{C}^+/^{13}\text{C}^+ = 60$), i.e. an equivalent hydrogen column density of $1.6 \times 10^{23} \text{ cm}^{-2}$, or an $A_v$ of about 100 mag.

We fit the total $^{12}\text{CII}$ and $^{13}\text{CII}$ profile by a two component model

\[ T_{mb} = \left\{ J_\nu(T_{bg}) \left(1 - e^{-\tau(T_{bg},N_{bg},v_{bg},\Delta v_{bg})}\right) \right\} e^{-\tau(T_{fg},N_{fg},v_{fg},\Delta v_{fg})} + J_\nu(T_{fg}) \left(1 - e^{-\tau(T_{fg},N_{fg},v_{fg},\Delta v_{fg})}\right) \]

where the optical depth as a function of velocity takes into account both the $^{12}\text{CII}$ and the three $^{13}\text{CII}$ hyperfine components (†), Gaussian profiles, and is calculated in the high density limit (Crawford et al. 1985). We assume a $^{12}\text{C}^+/^{13}\text{C}^+$ abundance ratio of 60 and allow $T_{ex}, N(C^+), \nu_{LSR}$ and $\Delta v_{FWHM}$ to vary. The foreground $T_{ex}$ is constrained to

† we use hfs-satellite intensity ratios as quoted in Fig. 1, different from the ones in Cooksy et al. 1986, which contains a typo
below about 80 K in order to absorb the background line down to the observed 55 K. The background has to be hotter than 160 K (RJ-corrected peak brightness temperature of the observed \(^{12}\text{CII}\)-profile). The least square fit cannot constrain the back- and foreground temperatures any further. Hence we display a first case (Model 1) with \(T_{bg} = 400\) K and \(T_{fg} = 80\) K (see Table 1). Another, extreme, case (Model 2) has the same \(T_{bg}\), but \(T_{fg} = 4\) K. It demonstrates that very low foreground temperatures are also consistent with the observed spectrum. The total column of \(\text{C}^+\) stays the same, being fixed by the observed \(^{13}\text{CII}\) line intensity.

On the order of 100 PDR layers would be needed to explain the large total column of \(\text{C}^+\) observed. In addition, the low temperature, large column of gas required to explain the foreground absorption is difficult to match with any reasonable standard PDR scenario.

<table>
<thead>
<tr>
<th>parameter</th>
<th>Model 1</th>
<th>Model 2</th>
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<tbody>
<tr>
<td>Fixed background</td>
<td>(T_{bg}) [K]</td>
<td>400</td>
</tr>
<tr>
<td>Foreground</td>
<td>(T_{fg}) [K]</td>
<td>80</td>
</tr>
<tr>
<td>Fitted background</td>
<td>(N(\text{C}^+)) ([10^{18} \text{ cm}^{-2}])</td>
<td>9.8(0.2)</td>
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<tr>
<td></td>
<td>(v_{LSR}) [km s(^{-1})]</td>
<td>10.32(0.02)</td>
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<tr>
<td></td>
<td>(\Delta v_{FWHM}) [km s(^{-1})]</td>
<td>3.24(0.03)</td>
</tr>
<tr>
<td>Foreground</td>
<td>(N(\text{C}^+)) ([10^{18} \text{ cm}^{-2}])</td>
<td>2.38(0.05)</td>
</tr>
<tr>
<td></td>
<td>(v_{LSR}) [km s(^{-1})]</td>
<td>10.13(0.03)</td>
</tr>
<tr>
<td></td>
<td>(\Delta v_{FWHM}) [km s(^{-1})]</td>
<td>2.95(0.08)</td>
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Figure 1. Spectrum and fit of the \(^{12}\text{CII}\) and \(^{13}\text{CII}\) emission (Model 1, Table 1). Left, bottom to top: residual, blow-up showing the \(^{13}\text{CII}\) hyperfines, and complete spectrum (red) and fit (green); right: spectrum (red), background (magenta) and foreground (blue).

References