Small Scale Structure in the ISM towards IC 2391 and NGC 6475

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Abstract. We describe UVES spectroscopic observations towards early-type stars located in the nearby open clusters IC 2391 (D=175 pc) and NGC 6475/M7 (D=301 pc), with resolution $\sim$80,000 and S/N ratio per pixel of $\sim$140 to $\sim$360. The aim is to investigate the small-scale structure variations within parts of the local ISM and determine how they are dependent on element and ionisation stage observed, thus providing information on cloud parameters such as structure and sizes. The data used are taken from on-line versions of the Paranal Observatory Project (POP: http://www.eso.org/uvespop). A total of 25 early-type stars (A and B-type) are present in our sample towards IC 2391 with 23 towards NGC 6475/M7, and enable us to probe differences in column densities on scales from $\sim$0.07–7.3-pc and $\sim$0.05–4.9-pc (in the respective clusters) for the optical transitions detected (Ti$\text{ii}$ (3383Å), Ca$\text{ii}$ (3933Å), Na$\text{i}$ (5889, 5895Å) and K$\text{i}$ (7698Å)). Towards NGC 6475 the Ca$\text{ii}$ column density is found to be constant to $\sim$0.15 dex over scales of $\sim$0.4–4-pc. A much greater scatter in the measurements for Na$\text{i}$ D is observed with differences of up to $\sim$0.45 dex in sightlines separated by $\sim$4 pc. In the future work we will perform the same analysis for Ti$\text{ii}$ and K$\text{i}$ towards both clusters.

1. Introduction

The properties of the interstellar medium on scales of $\sim$1 pc still remain poorly understood. In some lines studied in the optical, it has been found that there is little variation in line profile strength over such small scales, in others prominent changes are observed (e.g. review by Lauroesch, this volume). Differences in observed column densities over small scales can be caused for example by actual density enhancements of elements in the gas phase, or by projection effects. In either case, observational data concerning possible variations need to be explained by any model of the interstellar medium.

The study of small scale ISM structure relies on the presence of closely separated and equidistant background sources with which the intervening gas is probed. Globular clusters are often used in this type of work, either in their cores, where the stars in the line of sight merge to form a near-continuous source over many arcseconds (e.g. Meyer & Lauroesch 1999, Smoker et al. 2002b), or
by using individual stars in their outer parts (e.g. Smoker et al. 2002a). An alternative approach uses stars within open clusters as the background sources (e.g. Points et al. 2004) and is the method used in this paper.

2. The Sample and Data Reduction

The current sample consists of A and B type stars located within two open clusters, IC 2391 at a distance of \( \sim 175 \) pc in which 25 stars were observed and NGC 6475 (also known as M7) with distance of \( \sim 175 \) pc in which there were 23 targets. Basic parameters for the two clusters are shown in Table 1. Because the clusters are quite close, this means that local gas can be probed although the observed lines are relatively weak. The minimum star-to-star separation on the plane of the sky is 0.07 pc for IC 2391 and 0.05 pc for NGC 6475 with the corresponding maximum star-to-star separations being 7.3 pc and 4.9 pc. Hence the current dataset samples sub-pc to pc scales although on a point-to-point basis only. Stars were observed using the UVES échelle spectrometer of the 8.2-m telescope Kueyen on the Very Large Telescope. The spectra cover almost the entire optical range at a resolution of \( \sim 3.75 \) \( \text{km s}^{-1} \) and have S/N ratios pixel\(^{-1}\) from \( \sim 140 \) to \( \sim 360 \). For the spectra we used the on-line versions of the POP spectra (POP; Bagnulo et al. 2003)\(^1\), as in our previous work on the POP survey (Hunter et al. 2006, Smoker et al. 2007). In the cases of the Na\(_i\) D and K\(_i\) (7698Å) transitions, telluric lines were removed as shown in Fig. 1. Many stars show some stellar absorption around Ca\(_{II}\) K or Na\(_i\) D. When these lines were broad they were simply removed by interpolation, although in a future paper these will be removed by the fitting of model spectra. After removal of telluric and stellar lines, column densities of the interstellar features towards each star were measured using the Apparent Optical Depth (AOD) method.

\[\text{Figure 1. Telluric line removal in the Na}\_i\text{ D and K}\_i\text{ lines towards IC 2391 and NGC6475.}\]

\(^1\)See also [http://sc.eso.org/santiago/uvespop/](http://sc.eso.org/santiago/uvespop/)
Table 1. Clusters studied. NGC 6475 is also known as M7.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>l</th>
<th>b</th>
<th>D</th>
<th>$E(B-V)$</th>
<th>$v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC 2391</td>
<td>270.37</td>
<td>-6.83</td>
<td>175</td>
<td>0.008</td>
<td>+16.04</td>
</tr>
<tr>
<td>NGC 6475</td>
<td>355.86</td>
<td>-4.49</td>
<td>301</td>
<td>0.103</td>
<td>-14.21</td>
</tr>
</tbody>
</table>

Figure 2. Optical transitions observed towards individual stars in IC 2391 and NGC 6475.

3. Results

Fig. 2 shows example spectra for four optical transitions towards a single star in the two clusters. There is obvious detection of Ti\textsc{ii} (3383Å), Ca\textsc{ii} K and Na\textsc{i} D in both clusters and possible detection of K\textsc{i} (7698Å) towards sightlines in NGC 6475, although the K\textsc{i} feature lies near a telluric line (see Fig. 1). Typical column densities measured in log(cm$^{-2}$) in Ca\textsc{ii} are $\sim$11.3 dex towards IC 2391 and $\sim$11.5 dex towards NGC 6475. For Na\textsc{i} D the corresponding value towards NGC 6475 is $\sim$11.9 dex. Towards IC 2391 there is only one obvious interstellar component; however in the NGC 6475 spectra, two components are visible, especially in Ca\textsc{ii} K. Fig. 3 shows the absolute value of the difference in the point-to-point values of column density at two positions against distance between these two positions. Currently we only consider the strongest lines of Ca\textsc{ii} K and Na\textsc{i} D for the cluster NGC 6475 are shown. Column densities were derived in all cases using the same velocity limits for the AOD calculation. Sightlines
that have a dominant stellar component in the spectrum have been rejected. It is immediately apparent from Fig. 3 that Na\textsc{i} D shows a much greater scatter in column density than does Ca\textsc{ii} K. Indeed, the Na\textsc{i} D line strength varies by up to $\sim$0.45 dex (a factor of $\sim$3) whereas the Ca\textsc{ii} line strength is constant to within $\sim$0.15 dex over scales from 0.4 to 4 pc, some of the scatter being caused by measurement error.

![Figure 3](image.png)

Figure 3. Absolute value of the star-to-star difference in the derived ISM column density in dex plotted against the star-to-star line of sight separation in pc for NGC 6475 for the Na\textsc{D} and Ca\textsc{K} lines.

4. Summary and Future Work

We have demonstrated that the on-line version of the POP survey data towards two open cluster fields can be used to investigate the interstellar medium on scales from $\sim$0.1–5 pc. Within one of the two clusters studied (NGC 6475), the Na\textsc{i} D line strength was found to vary much more than Ca\textsc{ii} K over all measured scales. Future work will perform the same analysis for the dominant ion Ti\textsc{ii} towards both clusters and for K\textsc{i} towards NGC 6475. Finally, given that there are two components observed towards NGC 6475, a Voigt component analysis will be performed to trace differences in the changes of the component strengths as a function of sky position.

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References