XMM-Newton RGS and Chandra LETGS Observations of the WHIM toward 1ES 1028+511

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Abstract
We report preliminary results on the detection of the Warm-Hot Intergalactic Medium (WHIM) along the line of sight toward the z=0.361 (Polomski et al., 1997) blazar 1ES 1028+511. 1ES 1028+511 was observed, with in outburst, for 150 ks with the low energy transmission grating in combination with the high resolution camera (LETGS) onboard Chandra. An additional 300 ks observation was obtained using the reflection grating spectrometers (RGS) onboard XMM-Newton. We report the detection of five absorption lines which can be attributed to the WHIM, and compare the results with those obtained from the WHIM along the line of sight toward Mrk 421 and theoretical predictions.

Observations
The XMM-Newton observation was split up in three different observations. Two of the three RGS observations have a high background. Exposure time and 2-10 keV luminosities are listed below:

<table>
<thead>
<tr>
<th>Date</th>
<th>expos. time</th>
<th>L (10**42 erg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/03/04</td>
<td>149.66</td>
<td>0.21 ± 0.03</td>
</tr>
<tr>
<td>21/06/05</td>
<td>101.416</td>
<td>5.54 ± 0.05</td>
</tr>
<tr>
<td>21/06/05</td>
<td>95.225</td>
<td>5.048 ± 0.005</td>
</tr>
<tr>
<td>24/06/05</td>
<td>104.209</td>
<td>6.033 ± 0.006</td>
</tr>
</tbody>
</table>

Absorption lines
Five absorption lines are detected in three out of the four spectra with more than 3σ significance. For fitting we use delta lines and \( \Delta \chi^2 = 1 \), i.e. 1σ = 68%. Below are listed the EW’s of these features and the most likely identification. The ionic column density for the WHIM identifications are also listed. There is a wavelength shift of about 0.07 Å between the LETGS and the RGS spectra. The wavelengths determined from the LETGS spectrum are quoted.

| \( \lambda_{\text{abs}} \) | EW (mÅ) | N (log cm\(^{-2}\)) | Redshift | Iden.
|-----------|----------|-----------------|---------|------
| 30.05 | 0.21 | N VII Ly\( \alpha \) | 0.28 |
| 31.05 | 0.25 | N VII Ly\( \alpha \) | 0.32 |
| 46.25 | 0.15 | C IV K\( \alpha \) | 0.12 |
| 48.80 | 0.21 | C IV K\( \alpha \) | 0.18 |

Oxygen region
Oxygen is the most abundant metal, about an order of magnitude more abundant than nitrogen. The 1σ upper limits to the ion column density for O VII and O VIII are given below:

<table>
<thead>
<tr>
<th>ion</th>
<th>Redshift</th>
<th>N (log cm(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>O VII</td>
<td>0.15</td>
<td>&lt; 18.1</td>
</tr>
<tr>
<td>O VIII</td>
<td>0.15</td>
<td>&lt; 16.5</td>
</tr>
<tr>
<td>O VII</td>
<td>0.21</td>
<td>&lt; 19.2</td>
</tr>
<tr>
<td>O VIII</td>
<td>0.21</td>
<td>&lt; 16.4</td>
</tr>
<tr>
<td>O VII</td>
<td>0.25</td>
<td>&lt; 15.4</td>
</tr>
<tr>
<td>O VIII</td>
<td>0.25</td>
<td>&lt; 15.2</td>
</tr>
</tbody>
</table>

The N VII ion column densities are significantly larger than the upper limit derived for O VII. Also the C V column densities are larger than the upper limits derived for O VII.

Conclusions

We detect five absorption features along the line of sight toward 1ES 1028+511, which we interpret as WHIM signatures. Due to the lower signal-to-noise ratio compared to the Mrk 421 spectrum, we only detect higher column density gas. Our derived 2σ upper limit on the column density of O VII is still consistent with the theoretical predictions of the number of WHIM absorbers systems toward a distance of z=0.361. The identification as N VII Ly\( \alpha \) of the 30.05 Å absorption line would indicate a 2σ order of magnitude overabundance of N. An alternative identification could be ISM O I of a galaxy at z=0.28. In a preliminary search for galaxies along the line of sight toward 1ES 1028+511 we found 7 intervening galaxies, of which only 2 have a redshift, one at z=0.044 and one at z=0.174. Neither thus has the required redshift of 0.28 or 0.32.