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, while 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.

Date	expos. time	L (10^{-11})	instr.
	ks	erg cm^{-2} s^{-1}	
11/03/04	149.86	6.21 ± 0.03	LETGS
21/06/05	101.416	5.54 ± 0.05	RGS
21/06/05	95.225	7.048 ± 0.005	RGS
24/06/05	104.209	6.033 ± 0.006	RGS

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. $1\sigma = 68\ \%$. 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.

λ_{obs} Å	EW mÅ	N_i log cm^{-2}	redshift	iden.
30.05	19±6	16.3±0.1	0.21	N VII Lyα
			0.28	O I Kα
31.05	27±7	15.9±0.2	0.25	N VII Lyα
			0.32	O I Kα
46.25	24±7	15.6±0.2	0.15	C V Kα
			0.12	C IV Kα
48.80	32±10	15.8±0.2	0.21	C V Kα
			0.18	C IV Kα

Line identification

The 30.05 Å and 31.05 Å are most likely O I Kα lines or N VII Lyα lines, although we cannot rule out a N VI Kα identification. O I Kα would indicate the detection of the interstellar medium in galaxies along the line of sight.

The 46.25 Å and 48.80 Å lines can be either identified as C V or C IV lines. We prefer the C V identification, as C IV would imply a lower temperature than expected. Furthermore, the 48.80 Å C V identification gives the same redshift as that derived for the 30.05 Å line, assuming it is N VII Lyα.

None of the absorption features detected can be identified as either the O VII resonance line or the O VIII Lyα line.

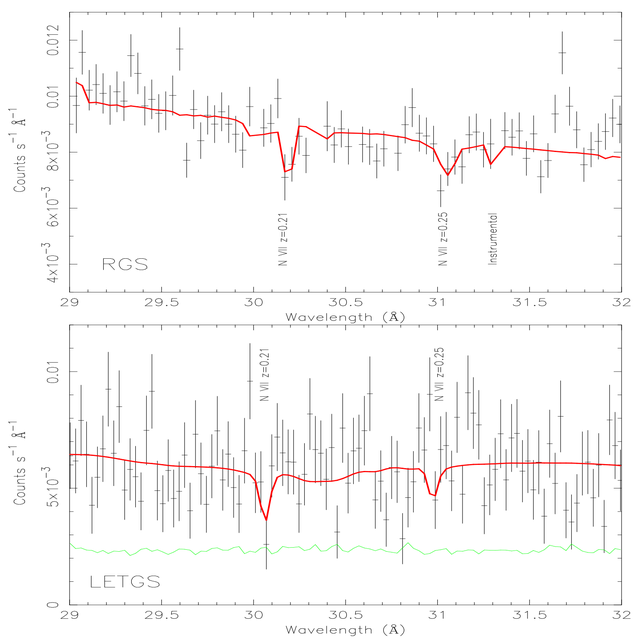
Oxygen

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.

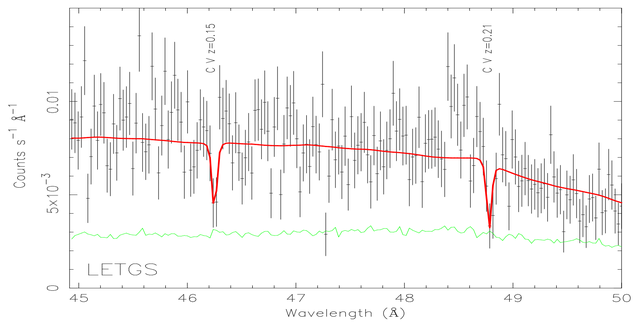
ion	redshift	N_i (log cm^{-2})
O VII	0.15	< 15.1
O VIII	0.15	< 16.5
O VII	0.21	< 15.2
O VIII	0.21	< 16.4
O VII	0.25	< 15.4
O VIII	0.25	< 15.2

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.

RGS spectra

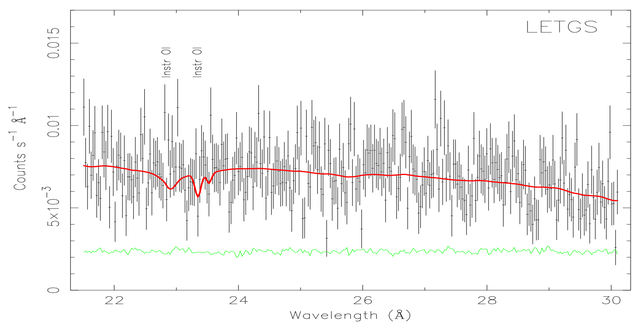


LETGS spectrum



The red line is the fitted model of an absorbed power-law plus two delta lines which can be identified either as C V or C IV lines. The thin green line is the subtracted background. Due to the long wavelength of these lines, they are only observed with the LETGS. However, they are present in both the positive and negative order.

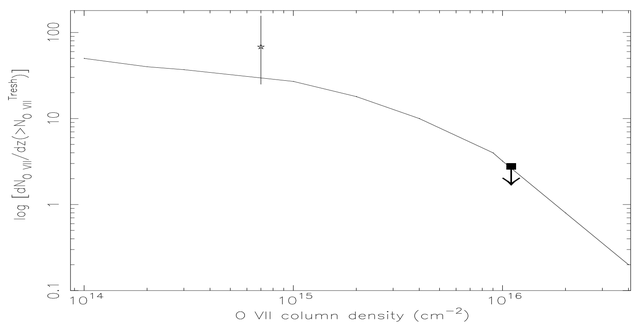
Oxygen region



The absorption feature at 28.8 Å is broadened, and not seen in the negative order of the LETGS. As a result, we do not consider this line as a detection of O VII Kα.

Comparison

In the figure we used the 2σ upper limit for the O VII column density determined for 1ES 1028+511 as well as the measured column density for Mrk 421. The probability of detecting at least 1 system, down to the redshift of z=0.361 with a 2σ sensitivity of N(OVII) $\geq 10^{16}$ cm^{-2}, is: 70.7 %, our non-detection is 1σ from expectation (Fang et al. 2002). Higher signal to noise spectra are needed to test the theoretical predictions.



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 Lyα of the 30.05 Å absorption line would indicate a 2 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.